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FACULTY OF MANUFACTURING

DEPARTMENT OF CHEMICAL ENGINEERING

Bioplastic Production from Avocado (*Persea Americana)* Seed Starch Reinforced With Cellulose from Coffee Husk

A Thesis Submitted to the Department of Chemical Engineering in Partial Fulfillment of the Requirements for the degree of Bachelor of Science (B.Sc.) in Chemical Engineering

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Department of Chemical Engineering

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Declaration

We, hereby declare that this thesis entitled: **Bioplastic Production from Avocado (*Persea Americana*) Seed Starch Reinforced with Coffee Husk Cellulose** was prepared by us, with the guidance of our advisor. The work contained here is our original work except where explicitly stated otherwise in the text, and this work has not been submitted, in whole or in part, for any other degree, and that all resources of materials used in this thesis have been duly acknowledged.

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Abstract

The use of conventional plastics for short-life applications is not sustainable due to the increase of plastic waste that evokes environmental concern. This is caused by the fact that plastics are derived from crude oil, which is a non-renewable fossil fuel, which subsequently produces high levels of environmental pollution. This research aims to study the production of bioplastic from avocado plant seed starch, which is reinforced with cellulose extracted from the coffee husk. Bioplastic from avocado seed waste and cellulose can reduce environmental issues from the excess use of conventional plastic. Starch is a natural biodegradable polymer that has the potential to replace synthetic polymers. In the present study a non-edible starch, which is extracted from avocado (Persea Americana) seed, with starch content of about 24.5% is a waste product of avocado processing and easily available in most part of the world. During the study, a bioplastic film was prepared by using starch gelatinization process followed by solution casting. A 20g of bioplastic film was produced by using starch gelatinization process followed by solution casting. About 8g of Samples of avocado seed starch, 1.2g of cellulose from coffee husk was used to prepare bioplastic film. Also 10ml of glycerol and 10ml of vinegar was incorporated in production of bioplastic as plasticizer and homogenizer respectively. The bioplastic film produced was characterized in terms of water uptake, water solubility, and biodegradability depending on the amount of cellulose and plasticizer used. In addition, 20, 27.5, 30 and 35% increase in water solubility were observed for sample bioplastics with plasticizer content of 2, 4, 6, and 8ml respectively was evaluated. The payback period and rate of return investment on this project were 4.24 years and 15.5%, respectively. This, indicate bio plastic produced from avocado seed starch is economically feasible. Bioplastic from a plant-waste can reduce environmental issues from the excess use of conventional plastic. It's sustainable, renewable and degradable features are some of the important properties making them suitable for producing bioplastic.

Key words: Bioplastic, Plant waste, Nano-Crystalline Cellulose, Avocado seed starch

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List of Abbreviation

Abbreviation	Description
AVS	Avocado seed
AVSS	Avocado seed starch
CH	Coffee husk
CHP	Coffee husk powder
CNC	Cellulose Nano crystalline
DIW	Deionized water
DP	Degree of polymerization
EBO	European Bioplastics Organization
RH	Relative humidity
PLA	Polylactic Acid
PET	Polyethylene terephthalate
PE	Polyethylene
PS	Polystyrene
PHA	Polyhydroxy Alkanoates
PCL	Polycaprolactones
PHB	Poly-3-hydroxybutyrate
PHBV	Poly Hydroxybutyrsyte co-hydroxyvalerate

CHAPTER ONE

1. Introduction

1.1. Background

Bioplastics are polymers that are capable of undergoing decomposition into CO_2, H_2O and organic compounds or biomass through predominantly enzymatic action of microorganisms. The market for these environmentally friendly materials is expanding rapidly with a growth rate of 10-20 % per year. The global market for biodegradable polymers is expected to rise at an average annual growth rate of 12.6 % to 206 million pounds by 2020. Biodegradable polymers are classified as agro-polymers (starch, chitin, protein) and bio polyesters (polyhydroxy - alkanoates, poly-lactic acid and etc.). They are mostly used to pack short shelf life products. Like fresh fruits and vegetables, and long shelf life products, Such as pasta and chips, which do not require very high oxygen and/or water barrier properties. The developments in the bio-based packaging offers a great potential to reduce our dependency on limited petroleum resources in order to realize the evaluation of the functional properties of a bio based material is essential before it can be used as an alternative for traditional film materials.(Mahawan, *et al.*, 2015).

Packaging waste, form a significant part of solid waste and has led to increasing environmental concerns, resulting in strengthening of various regulations aimed at reducing their impact. A wide range of conventional oil-based polymers is currently in use in almost every industry. Oil based polymers are virtually non-biodegradable and are difficult to recycle or re-use. In the recent years, the use of bio-based polymers in packaging has generated interest among researchers as they bring a significant contribution to sustainable development with a wider range of disposal options.

Developing a polymer with durability, that matches the product shelf life, is one of the toughest challenges faced by packaging industry in its efforts to produce bio-based primary packaging. The bio-based packaging material must remain stable without changes in mechanical and/or barrier properties and must function properly during storage, until disposal. Plastic films are highly appreciated in the food industry because of their wide range of properties and at present, it is not possible to replace plastic packaging completely from the market.

1.2. Statement of the Problem

Nowadays, demand for plastic products is increasing. The need for such large quantities of conventional plastics and their dominance over other materials is due to their excellent lifelong properties, which include resistance to chemical reactions, especially enzymatic reactions. However, the use of conventional plastics for short-life applications is not sustainable due to the increase of plastic waste that evokes environmental concern. This is caused by the fact that plastics are derived from crude oil, a non-renewable fossil fuel, which subsequently produces high levels of environmental pollution.

Concerns regarding environmental deterioration as well as issues regarding the sustainability of fast depleting petroleum resources used to make conventional plastics have forced the scientific community to focus on developing and manufacturing new and novel 'green' materials that are fully biodegradable and derived from renewable, plant-based resources. In the present study a non-edible starch, extracted from avocado (Persea Americana) seed starch, a waste product of avocado processing, was developed for fabricating 'green' materials so-called bioplastic. (Muneer, F. 2014).

1.3. Research Question

- What is the effect of the ratio of the cellulose to starch on bioplastic production?
- What is the influence of the cellulose and glycerol on water solubility and water uptake of bioplastic produced?
- How the extraction process of microcrystalline cellulose is affected by alkali treatment and acid hydrolysis?
- How the ratio of starch to cellulose affects the drying time of bioplastic produced

1.4. Objectives

1.4.1. General Objective

The general objective of this study is to produce bioplastic from avocado seed starch by reinforcing with cellulose from coffee husk.

1.4.2. Specific Objectives

- To assess the influence of the cellulose and glycerol on water solubility and water uptake of bioplastic produced
- To identify the effect of cellulose to starch ratio on drying time of the bioplastic produced.
- To determine the yield of isolated starch and cellulose from avocado seed & coffee husk respectively.
- To determine the feasibility aspects of bioplastic production from Avocado seed starch.

1.5. Significance of the Study

Bioplastic from avocado seed waste and cellulose can reduce environmental issues from the excess use of conventional plastic. It has many advantages including reducing tool wear, low cost, and density per unit volume compared to conventional or synthetic fibers. Furthermore, it's sustainable, renewable, and degradable features are some of the important properties making them suitable as filler in polymer composites. Biodegradable polymers made from renewable resources are a possible alternative to reduce the number of landfill waste and other environmental issues. Starch is a natural biodegradable polymer that has the potential to replace synthetic polymers used for limited-time applications, i.e., disposable packaging and cutlery. It is commonly found in the form of biodegradable films for varied applications, as it is a renewable, abundant, and inexpensive material. Avocado seed usually discarded, has around 30% starch content. Hence, it serves as a potential starch source.

CHAPTER TWO

2. Literature Review

2.1. Overviews of Bioplastics

Significant commercialization of bioplastics only began in the middle of the nineteenth century. The American inventor, John Wesley Hyatt, Jr., was looking for a substitute for ivory in the manufacture of billiard balls, and in 1869 patented a cellulose derivative for coating non-ivory billiard balls. That attempt, however, was affected by the coating's flammability; balls were occasionally ignited when lit cigars accidentally came into contact with them. Hyatt continued working on the project and soon developed celluloid, the first widely used plastic, now most widely known for its use in photographic and movie film. The history of plastics changed dramatically in the early 1900, as petroleum emerged as a source of fuel and of chemicals. The early bioplastics were simply displaced by plastics made from synthetic polymers. (Alves et al., 2015).

Going into the history, there was virtually no existence of plastics in the world, one century ago and in last 90-100 years they have entered nearly all aspects of our life. Plastic is the most useful synthetic manmade substance, derived from the elements extracted from fossil fuel. Plastics are the polymers, which become mobile on heating and can be cast into various molds. These plastics are typical materials of the last century and have made a tremendous growth of some hundreds of tones/year at the beginning of the 1930s to more than 150 million tones/year at the end of the 20^{th} century with 220 million tons forecast by 2025. (Journal of Hill Agriculture, 2017)

The features associated to plastics are beyond dispute however, increasing concerns about the preservation of our ecological systems, their effects on human health, increasing pressure on limited petroleum resources and non-biodegradable nature of plastics. In addition, plastic recycling has a negative eco-balance, which requires high energy and difficulties arise from contaminants and fiber reinforcements due to production of complex multi-phased products during plastic recycling which have compounded the problem further. Further, use of polymers

having longer durability in products with a short life span i.e. food items etc. is not advisable. All these concerns have given birth to the development of more sustainable alternate.

At the present, the main focus of the plastics industry is to develop novel polymeric material having properties comparable to their conventional counterparts but at the same time should have additional advantage of at least some level of biodegradability. Innovative products have slowly started to infiltrate the market and have started to replace conventional polymers, particularly for short-term applications (fresh food packaging, agriculture etc.). The potential of biodegradable polymers has been recognized for a long as they provide an interesting solution to overcome the limitation of conventional plastics and at the same time also helps in reduction of CO_2 emissions. The bio based polymers still have not entered the market with their potential applications as high production costs and sometimes their underperforming properties still restricts their use. Overall, this review focuses on different classes of these biopolymers, their production technology, potential application in the food packaging and their biodegradation (Jawaid, M. and Abdul Khalil, H. 2011).

2.1.1. Bioplastics Place in the Current Age of Plastics

For bioplastics to become practical, they must have properties that allow them to compete with the current plastics on the market: bioplastics must be able to be strong, resilient, flexible, elastic, and above all, durable. It is the very durability of traditional plastics that has helped them in the marketplace, and has been a major goal of plastics research throughout the years. However, it is exactly this durability that now has people increasingly worried. Now that we wrap our sandwiches in bags that will still be around when the sandwich, and even the person who ate it, are long gone, many people are wondering: have we gone too far? Current research on bioplastics is focusing on how to use nature's polymers to make plastics that are programmed degradable: in other words, how to make products that allow you to control when and how it degrades, while insuring that the product remains strong while it is still in us (Mohamed et al., 2021).

2.1.2. Potential of Bioplastic Production in Ethiopia

Bio-plastic has a significant contribution. Thus, developing in a wider range of disposal at lower environmental impact worldwide but, in Ethiopia it is not considered as legislative attention even Ethiopia has many options to produce bio-plastics from agro – industrial wastes and other byproduct those has a potential to produce and commercialize this environmentally friendly bio-plastic which can eliminate environmental problems. Also, it creates job opportunities from raw material collection to producing the main product.

2.1.3. Challenges and Opportunities for Development of Bioplastic from Renewable Resource

Over the last several years, production of polymers from renewable resources has shown significant growth. Some of the plastics produced from renewable resources such as vegetable oil, corn, and pea starch have been synthesized by microbes and are known as bioplastics. Their development is driven by current demands to replace fossil fuel-based polymers. It all starts with growing plants such as sugar cane and corn that are high in starches. Limitation in fossil fuel resources, price volatility, impact on the environment, and waste disposal problems are some of the main reasons for this shift toward bio-based plastics. The environmental impact caused by petroleum-based packages have been increasing researches aiming the use of biodegradable materials based on renewable resources (Moad, 2011). Natural fibers have recently become attractive to researchers, engineers and scientists as an alternative reinforcement for fiber reinforced polymer composites. Due to their low cost, fairly good mechanical properties, high specific strength, non-abrasive, eco-friendly and bio-degradability characteristics, they are exploited as a replacement for the conventional fiber, such as glass, aramid and carbon. The tensile properties of natural fiber reinforce polymers (both thermoplastics and thermosets) are mainly influenced by the interfacial adhesion between the matrix and the fibers. Several chemical modifications are employed to improve the interface matrix–fiber bonding resulting in the enhancement of tensile properties of the composites (Mohamed et al., 2021).

2.2. Biodegradable Polymers

According to the European Bioplastics Organization (EBO), bioplastics are the "Plastics based on renewable resources (bio based) or plastics which are biodegradable and/or compostable". These biopolymers undergo decomposition into CO_2, H_2O and inorganic compounds or biomass under natural or stimulated conditions through predominantly by enzymatic action of microorganisms. (Tokiwa, et al., 2009)

Further, for a polymer to be categorized as bioplastic, the following four criteria must be fulfilled.

- **Chemical characteristics**: At least 50 % of its final composition should be necessarily organic matter.
- **Biodegradation**: The developed polymer should degrade by a minimum of 90 % of its weight/volume within 6 months under stimulated composting conditions.
- **Eco toxicity**: Un-degradable residuals of biopolymer after biodegradation for 6 months should not be a potential threat to the growth of plants.
- **Disintegration:** the bio-based polymer should, at least within a timeframe of 2 months, fragment microscopic undetectable components (< 2 mm) under controlled composting condition

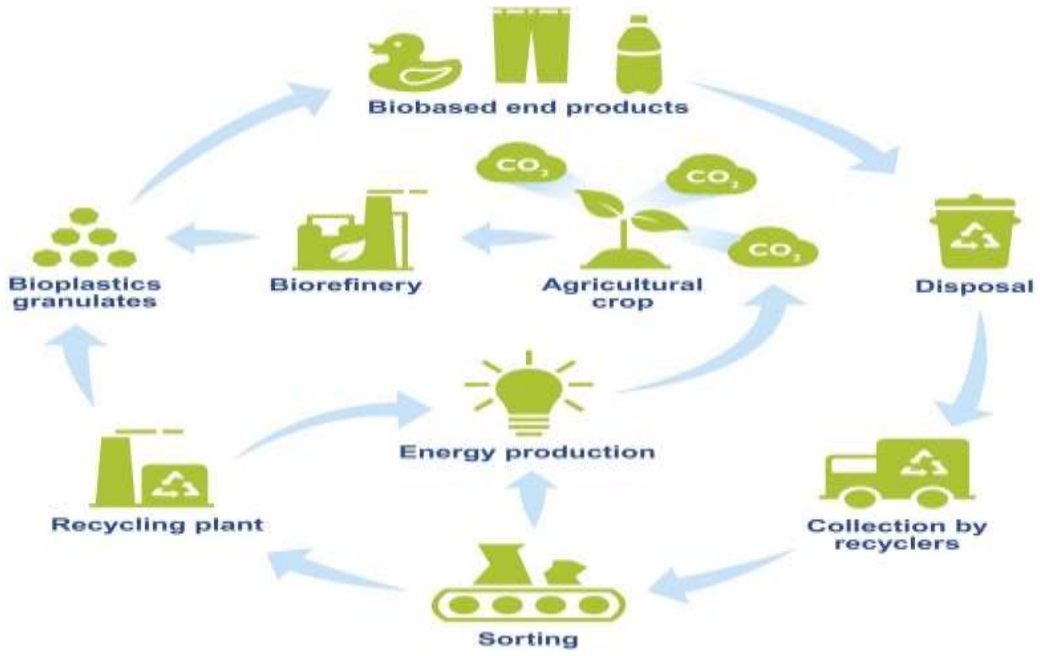


Figure 2.1. Life cycle of biodegradable plastics

Source: FKUR, (1992)

Biodegradable are considered as substitutes to degradable plastics since they have many characteristics that favors them concerning their environmental benefits. The figure above shows the life cycle of a biodegradable plastic.

2.3. Characterizing Biodegradability of Polymers

During examination of the biodegradability of a material, results cannot depend solely on chemical analysis of the polymer. The effects of the environment also should be considered. For simplification, biodegradation environments can be separated into environments where; oxygen is absent (anaerobic), and oxygen is present (aerobic).

These are then further subdivided into terrestrial and aquatic environments. Microbial action and hence biodegradability is affected by the:

- Oxygen uptake rate
- Thermal conditions
- Availability of water
- Chemical environment & Predominance of microorganisms

Several analytical approaches have been established to measure the extent and nature of biodegradation. These characterization systems are intended to study the physical, chemical, and mechanical properties of the polymer before and after degradation, which will aid in understanding the degree in addition to the mechanism of degradation. Since the characteristic exposure setting involves incubation of a polymer substrate with enzymes or microbes. Measurements are hence limited with regards to the reactive products, the microorganisms, or the substrates.

Universal approaches existing for the study of biodegradation processes include:

- Monitoring reaction products
- Monitoring the depletion of substrates
- Monitoring microbial growth
- Monitoring changes in substrate properties

2.4. Classification of Biodegradable Polymers

Various classification system based on different criteria's have been proposed to classify of these biopolymers as they can be derived from a large number of renewable sources and it is difficult to restrict them in a single class. The following figure shows the classification of biodegradable polymers based the source and methods used.

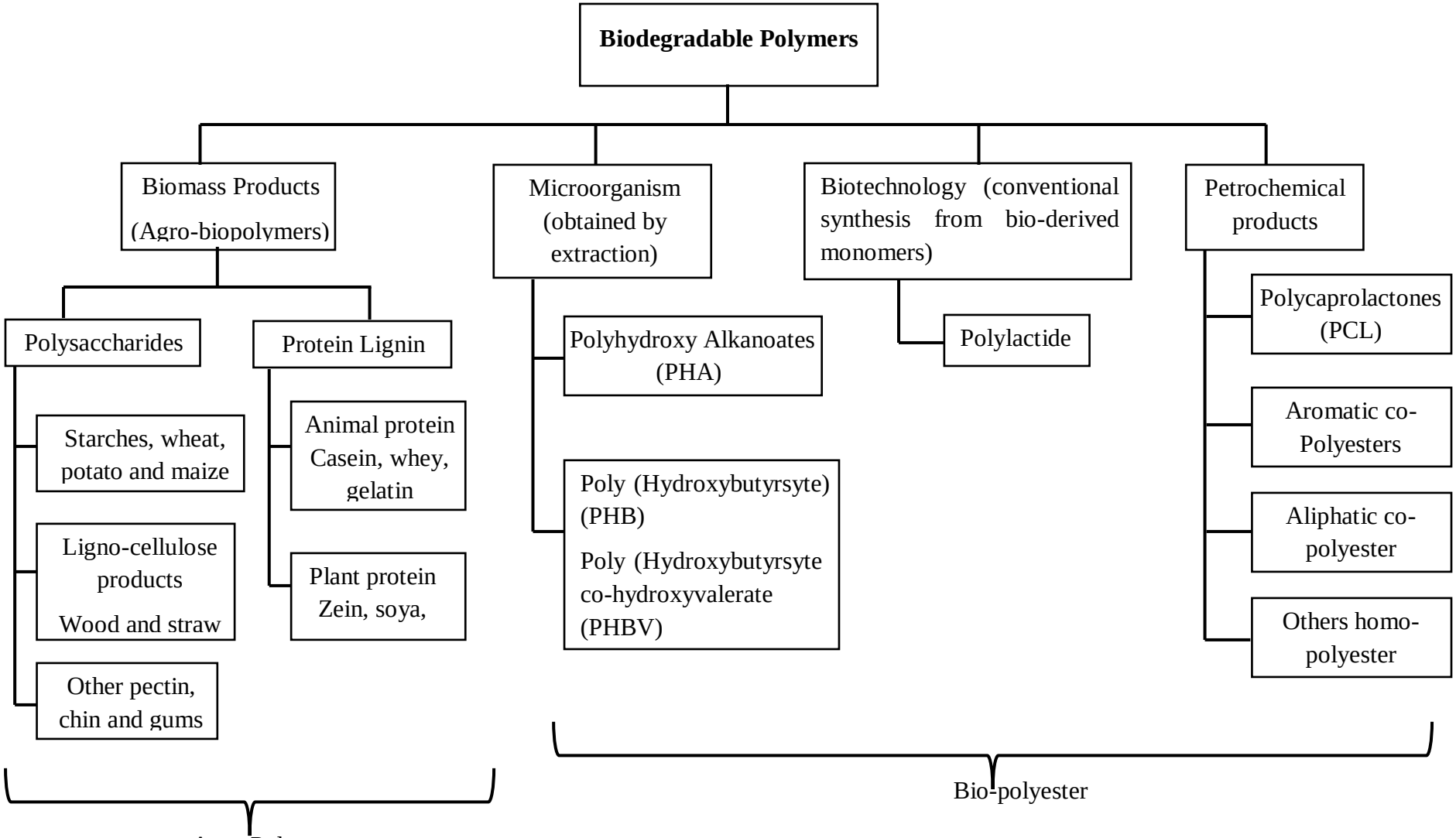


Figure 2.2. Classification of Biodegradable Polymers

Source: Averous, & Pollet, (2012).

The classification system based on their origin in Figure 2.2. divides the biopolymers into four major categories of which the first three are derived from renewable resources and the last one is a blend of biopolymer and commercial polyesters. Broadly these biopolymers can be subdivided into two broad categories i.e. agro-polymers (category 1) and biodegradable polyesters (categories 2-4) or bio-polyesters. (Averous, & Pollet, 2012).

2.4.1.1. Classification of Biodegradable Plastics Based on Source

Biodegradable plastics can be classified as;

1. **Cellulose Based Plastics**

Cellulose based plastic are plastics produced from cellulose resources such as wood and other plant materials. The mechanism behind producing cellulose-based bioplastic involve the conversion of glucose found in the cellulose from the plant or biomass into hydroxymethylfurfural (HMF). However, this technology is quite expensive and still requires a lot of research before commercial applications (Gironi, and Vincenzo, 2011).

2. **Aliphatic Polyesters**

Aliphatic polymer has similar characteristics as Polyethylene (PE) and Polypropylene (PP). They are used for the production of beverage bottles or trash bags. This polymer can be manufactured by conventional plastic process and are resistant to high temperatures up to 260oC. However the polymer is also resistant to microbial degradation (Gironi, and Vincenzo, 2011).

3. **Polylactic Acid (PLA) Plastic**

PLA is derived from natural resources such as corn or sugar cane (glucose). It can be processed easily on conventional petroleum plastic machinery and has many similar characteristics. PLA usually comes in granular forms and can be used along processing lines to manufacture foils, cups and bottles.

4. **Poly-3-Hydroxybutyrate (PHB)**

Poly-3-hydroxybutyrate (PHB), a biopolymer, is a polyester produced by some microorganisms that feed on starch or a source of glucose. PHB shows interesting characteristics as an alternative to degradable plastics because it is a transparent film at a melting point higher than 130^{o}C and is completely biodegradable.

5. Polyethylene Derived from Biomaterials

Polyethylene can be derived from biomaterials such as the fermentation of corn or sugarcane. It is a polymer of ethylene which can be produced from ethanol. The polyethylene obtained from the organic raw materials is similar to the petroleum derived polyethylene. However the polyethylene does not biodegrade but can be recycled.

6. Starch Based Plastics

Starch based plastics are plastic produced from starch which possesses the ability to observe plastic properties similar to thermoplastic polymers. Around 50% of the market of bioplastic is starch-based plastic or bioplastic. It is currently the most important and extensively used bioplastic used.

2.5. Factors Affecting Biodegradability

Some factors affecting biodegradability including physical and chemical characteristics are listed below, however some research has shown many variants from this norm. Platt (2006), Tokiwa et al. (2009). and Arutchelvi et al., (2008) gave these factors :

- The surface presented for attack and physical state of the plastic
- Crystallinity and amount of amorphous regions
- Hydrophilic nature of the polymer & interaction with other polymer blends
- Pendant groups, their chemical action and their position
- Chemical linkages in the polymer backbone
- Density, molecular weight and size of the polymer
- Chemical activity of end-groups & Melting temperature
- Stereo-chemistry of the monomer units along the polymer chain

2.6. Advantage and Disadvantage of Bioplastic

2.6.1. Advantage of Bioplastic

The pros or advantages of bioplastics are;

- Bioplastics are made from plant raw materials instead of petroleum oil, the raw material used to make conventional plastics
- Bioplastic are renewable and sustainable unlike oil which is a limited and finite resource
- Bioplastics are biodegradable, compostable and cheaper than normal plastics especially with the soaring oil prices
- Reduced CO_2 emissions, It takes only 0.8metric tons of CO_2
- Reduced carbon footprint, the carbon footprint of manufacturing bioplastics is reportedly 75% lower than that of PET and PS alternatives i.e. their manufacture is kinder to the environment
- Bioplastics are non-toxic and won't leach chemicals into food, according to a study conducted by the National Center for Biotechnology Information in America; plastics including BPA free plastics leach estrogen-like chemicals into food
- There are a variety of Zero waste end of life options for bioplastics, bioplastics can be recycled and cleanly incinerated and industrially composted. This is makes bioplastics a great material for food packaging as used packaging does not require cleaning since food and packaging can be composted or incinerated together.

Figure 2.3. Some of the product of bioplastic used in our daily activities

(Gerngross, T and Slater,S, 2000)

2.6.2. Disadvantage of Bioplastic

The cons or disadvantages of bioplastic are;

- Growing demand for bioplastics creates competition for food sources, contributing to the global food crisis.
- Bioplastics won't biodegrade in landfill. Unfortunately, landfills remain the last stop for many plastics. Since, landfill; need industrial composter to decompose bioplastic.
- Bioplastics contaminate plastic recycling streams. Most bioplastics are compatible with existing recycling systems. Bioplastic PET is compatible with PET recycling streams and bioplastics PE is compatible to the PE recycling stream.
- Area not set up for bioplastics, most developed countries in the world have recycling deposits but hardly any at all have industrial composter

2.6.3. Comparison Study

Biodegradable plastic derived from starch are two types of plastics that can be used for the production of plastic carry bags. However, they both have their qualities and weaknesses.

Table 2.1. Advantage comparison of degradable plastics and starch-based plastics

Degradable plastics	Starch-based plastics
They are light weighed and can be used for the production of plastic carry bags.	They do not cause death for marine animals such as the tortoise in the sea
They have strong mechanical and physical properties in contrast to starch based plastics	They do not affect the environment in the form of water pollution or environmental pollution
They are made from nonrenewable raw material such as crude oil which make them not environmentally sustainable	Has a considerable cost thus affecting it economic sustainability

Source: (Gerngross, T. and Slater, S. 2000)

Table 2.2. Disadvantages comparison between of degradable plastics and starch-based plastics

Degradable plastics	Starch-based plastics
Degradable plastics are sometimes not biodegraded thus contributing to the increasing amount of solid waste in landfills where they remain unchanged	They show weaker mechanical and chemical properties as compared to degradable plastics.
They generate a lot of solid waste though some degradable plastics can be recycled	Has a considerable cost thus affecting it economic sustainability
Degradable plastic production is very energy intensive processes requiring a large amount of energy	They do not have a long life time since they degrade in the presence of environmental conditions such as microorganism and moisture

Source: (Gerngross, T. and Slater, S. 2000)

2.7. Starch and Its Properties

Starch is a white, tasteless carbohydrate food substance building up from hundreds or thousands of D-glucose molecules. It does not dissolve in cold water while at higher temperature such as heating it with excess water under pressure, starch granules collapse and an opalescent colloid solution known as gelatinization. The gelatinization temperature of the starch is influenced by plant genetic and environmental factors. It is the storage carbohydrate in plants being in different amount in various plant species and varieties. It is the end product of plant carbon assimilation. It accumulates in granules such as amyloplasts in the roots, tubers, stems, seeds and fruits of plants.

Starch consist of two constituents, these are amylose and amylopectin, which are high molecular weight polymers of D-glucose bound by α-1,4-glycoside linkages. The physical and chemical properties of amylose and amylopectin are different. Their ratio affects viscosity, shear resistance, gelatinization, textures, solubility, tackiness, gel stability, cold swelling and retro gradation properties of starch. All these properties have high importance in the suitability of the starch of a given avocado seed for various processing and use.

2.7.1. Chemical Structure of Starch

Starch is one of the most common food sources in our society. It is most produced and preserved in many parts of plants especially in roots, fruits and seeds as energy storage. Among all plants, rice, maize, potato, cassava, wheat are the most common sources for starch. Starch exists in the form of granules with sizes ranging from 2 μm to 100 μm.

Starch is made by combining glucose repeat units. There are mainly two types of molecules within starch, linear amylose and branched amylopectin as shown in Figure below. Amylose is a linear molecule with (1-4)-α-linkage with average molecular weight ranging from 105 to 106. It exists in a helix form and has no branches. Compared to amylose, amylopectin molecules are highly branched with relatively high molecular weight between 106 to 107 g/mol and exist in double helical structure. Glucose units in amylopectin can both be bonded with α-(1-6) or α-(1-4) linkages. As a highly branched structure, amylopectin exists predominantly in crystalline form.

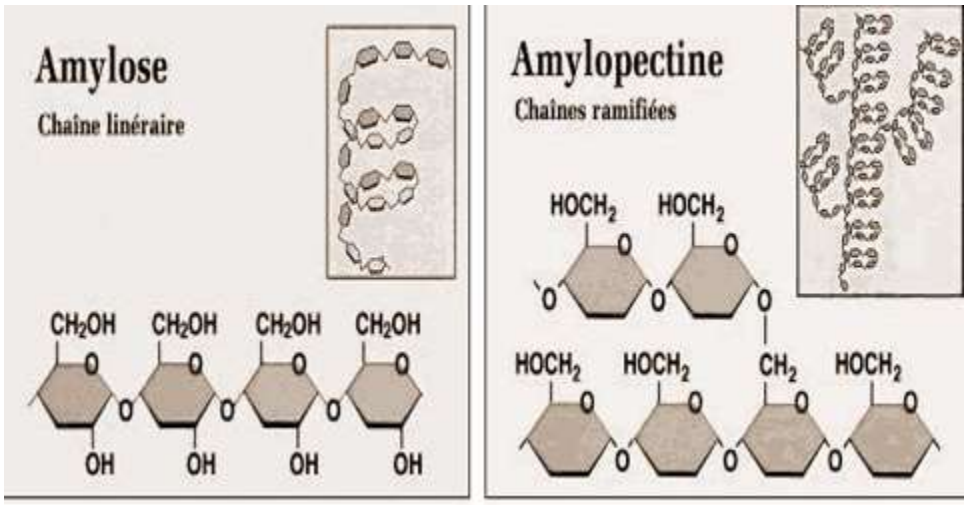


Figure 2.4. Structure of amylose and amylopectin molecules

(Gerngross, T. and Slater, S)

The proportion of amylose and amylopectin varies in different plants, with generally 20% - 30% of amylose and 70%~80% of amylopectin. The different proportions of amylose and amylopectin give rise to various structures and properties to starch.

2.7.2. Starch-Based Plastics

As a bio-based polymer, starch is considered to be environmentally friendly because of its low or zero greenhouse gas emissions. It is one of the favored resins for green composite fabrication where the biodegradability and non-dependence on petroleum are desirable. Figure shows the global production capacities of bioplastics in 2019. As can be seen in Figure, it has been estimated that about 2.1 million tons of bioplastics were globally manufactured in 2019 and almost 21.3% of them were starch-based. Same report also predicted that starch-based plastics will continue to grow and be used more in diverse fields including flexible packing, medical treatment, construction and electronic devices.

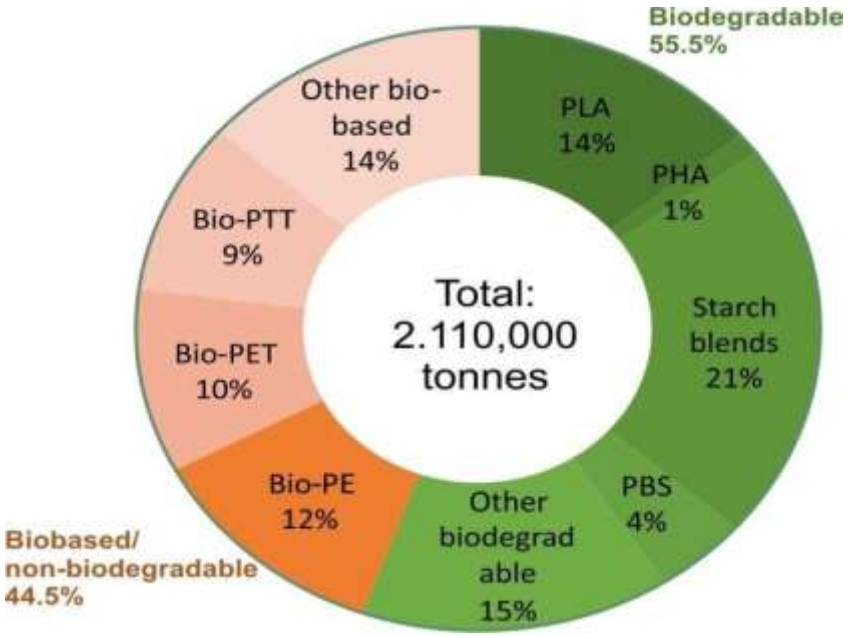


Figure 2.5. Global production capacities of bioplastics in 2019

(Plastics Europe, Plastics – the Facts. 2019)

2.7.2.1. Modification of Starch-Based Materials

In spite of the inherent advantages and increasing demand of starch-based plastics, several challenges still need to be addressed before large scale production of starch-based composites can be possible. First, pure starch has very low mechanical properties which makes it difficult to process. Second, the hydroxyl groups present in starch-based materials allow them to readily absorb moisture, which lowers their fracture stress as well as glass transition temperature (Tg). Most plasticizers used for starches are themselves hydrophilic and their addition further increases

the moisture absorption and lowers strength and Tg even further. To overcome these problems, some modifications such as physical blending with reinforcing particles or fibers/fibrils, chemical modifications including crosslinking, esterification and graft copolymerization, etc., have been developed during last couple of decades.

A. Plasticizer

Pure starch resins are very brittle, difficult to bend and very weak. However, when plasticizers such as glycerol or sorbitol are added to starch, the strong intermolecular hydrogen bonding is disrupted. In addition, the large amount of free volume brought in by the plasticizers results in lower Tg and significantly higher flexibility for the starch-based materials. This allows raw starch to be processed as thermoplastic starch (TPS). Although high flexibility and fracture strain of TPS are obtained. It still has low mechanical properties (1~10 MPa fracture stress and over 100% fracture strain) compared to traditional polymers such as PE (14~40 MPa fracture stress and over 100% fracture strain), PP (26~41 MPa fracture stress and over 100% fracture strain), PLA (60 MPa fracture stress and 3.5% fracture strain) and PBS (27 MPa fracture stress and 16% fracture strain). As a result, other modifications have to be done to make the application of starch-based composites feasible. (Hongsriphan, N. & Pinpueng, A. 2019)

B. Blending with other polymer and reinforcements

One of the most common physical modifications is blending with hydrophobic materials. Starch had been blended with other biodegradable polymers including PLA, PCL, etc. Synthetic biodegradable polymers normally have higher cost but excellent mechanical properties and water stability. As a result, the proportion of the synthetic polymer/starch blend could be adjusted to reach the requirements of low cost, high mechanical properties as well as water stability. Compatibilizers, such as maleic anhydride (MA) are generally needed to improve the compatibility between starch and other hydrophobic synthetic degradable polymers.

Besides blending with synthetic polymers, starch-based plastics can also be blended with reinforcements to further improve their strength, modulus (stiffness) and decrease their water absorption. Common reinforcing agents include rigid particles and fibrous materials. Rigid particles such as montmorillonite, fly ash, chitosan and other metal particles can be well controlled to disperse uniformly in starch resins. The particle size, however, should be strictly controlled to avoid defect formation and stress concentration. Fibrous materials are by far the

most common reinforcing agents. Within biodegradable materials, cellulose fibers have high specific stiffness and can hydrogen bond well with starch-based materials because of their chemical similarity. (Ostafińska et al,. 2017)

C. Chemical Treatments

Besides physical blending, several chemical modifications of various starches have also been studied for many decades. Starch grafted copolymerization, esterification and crosslinking are some of the common chemical methods which reduce the exposure of hydroxyl group of starch molecules and, thus, address the inherent hydrophilicity related problems of starch. Each glucose unit in starch has three hydroxyl groups. One of them is a primary group and the other two are secondary hydroxyl groups. The primary groups are much more reactive than the other two and are more amenable for chemical modifications. As a result, most chemical modifications to transform cellulose into different structures involve the primary groups. (Ostafińska et al,. 2017)

2.7.2.2. Starch Made from Plant Waste—Avocado Seed

Until now, starch-based composites have been considered to be good substitution for petroleum based materials. Among all kinds of starch sources, corn, potato, cassava have been most used and most studied. However, since these starches are edible for humans and animals, questions have been raised about taking food away to make composites for construction or packaging.

Indeed, this can hurt poor people the most. Non-edible starch, which does not impact the human daily diets would obviously be a better choice. Also, since most available non-edible starch sources are waste or unusable by-products, using them should not only be more sustainable but also solve the waste issues, making this a win-win solution. Studies on starch-based waste by-products have been already done on mango seeds, jackfruit seeds, horse chestnut, etc. For example, horse chestnut starch was extracted to make thermoplastic starch by melt blending with glycerol. However, the mechanical properties were relatively low compared with other common starches with fracture stress of only 2-3 MPa and fracture strain of 1%. (Lubis, et al., 2018), used jackfruit seeds to extract starch and blend with 20 wt. percentage chitosan and obtained strength of 13.5 MPa. Patil and Netravali, created bio-plastics from mango seed kernel starch with 16 MPa fracture stress after crosslinking with 1,2,3,4-butane tetra carboxylic acid (BTCA). Higher fracture stress of 50 MPa was obtained by reinforcing it with 40 wt. % micro-fibrillated cellulose (MFC).

2.7.2.3. Physiochemical Properties of Avocado fruit

Table 2.3. Physicochemical parameters of the different parts of Avocado fruit

Parameter (percentage)	Pulp	Skin	Seeds
Moisture %	70.83± 3.53	69.13± 2.58	54.45± 2.33
Ash %	1.77± 0.16	1.50± 0.08	1.29 ±0.03
Proteins%	1.82± 0.07	1.91± 0.08	2.19± 0.16
Fat %	43.5± 4.62	2.20± 1.65	14.7± 0.32
Total soluble solids%	43.5 ± 4.62	3.01± 2.03	3.54± 1.97
Acidity %	1.07 ± 0.02	2.05 ± 0.24	2.67± 0.17

Source: Journal of Agricultural science, (2013)

The moisture content is one of the most important indices evaluated in foods, especially fruits. It is a good indicator of their economic value because it reflects solid contents and serves to assess its perishability. The results indicate that the avocado pulp has higher water content (70.83%) followed the skin (69.13%) and seed (54.45%). The fat and ash quantified in pulp were significantly superior to those found in the skin. The seed was the part of the fruit that had higher amounts of total protein (2.19%) and lowest ash content (1.29%) nevertheless, relative to its fat content, showed higher percentages compared to those found on the exocarp (skin).

According to (Hernández-Muñoz *et al*. 2006), the total acidity is a measure of the organic acid content. The predominant acid found in avocados is tartaric acid although, theoretically, every species capable of donating a proton, including fatty acids, also contribute to the total acidity of the fruit.

2.8. Coffee Husk and Cellulose

Coffee is one of the top commodities produced and commercialized worldwide and the processing of coffee generates significant amount of agricultural waste ranging from 30% to 50% the weight of the total coffee produced, depending on the type of processing. Coffee husks is one of the major solid residues obtained after de-hulling of coffee cherries during dry or wet processing.

It is also referred to as coffee chaff, which is the dried skin of the bean during the roasting process. Coffee husks contain 33.4% cellulose, 23.7% lignin, 29.7% hemicellulose and 6.2% ash. This mainly focus on the contain of cellulose, which is used for strengthen or reinforcing the starch in the production of bioplastic.

Cellulose is the most abundant organic chemical on the face of the earth. It is a glucan polymer of D-glucopyranose units, which are linked together by β- (1-4) glucosidic bonds. The building block for cellulose is cellobiose, since the repeating unit in cellulose is a two-sugar unit. The number of glucose units in a cellulose molecule is referred to as the degree of polymerization and the average DP for plant cellulose ranges from a low of about 50 for sulfite pulp to approximately 600, depending on the determination method used (Stamm, A. 1964). Cellulose molecules are randomly oriented and have a tendency to form intra-crystalline regions. Most plant-derived cellulose is highly crystalline and may contain as much as 80% crystalline regions. The remaining portion has lower packing density and is referred to as amorphous cellulose. To extract cellulose from coffee grounds a catalyst is used to oxidize and break down the coffee beans cell wall. The resulting microscopic cellulose fibers is a uniform structure, which could easily be mixed into polyvinyl alcohol-polymer to produce the biodegradable plastics.

Figure 2.6. Coffee husk-source of cellulose

Source: Royalty-free stock photo, (2019)

2.8.1. Reinforcement Using Cellulose-Based Fibers

2.8.1.1. Chemical Structure of Cellulose

To make fully green biodegradable composites, reinforcements used should not only provide excellent mechanical properties but should also be fully biodegradable. As the most common bio based biodegradable polymer, cellulose meets both these criteria. Cellulose is a linear chain polysaccharide with D-glucose units linked with β 1→4 bond, which is different from the α 1→4 link of amylose in starch. Compared with amylose, the glucose repeat units in cellulose are rotate 180^{o} for each successive glucose. The bonds limit the free rotation of C-O-C (ether) bond, which gives the structure higher stiffness and strength. Also, β 1→4 bonds allow the formation of stronger intermolecular hydrogen bonds resulting in high stiffness of cellulose molecules (Kalita. & Netravali, 2017).

2.8.1.2. Cellulose-Based Microfibers and Nanofibers

I. Cellulose-Based Microfibers

Plant derived cellulose fibers have become popular in many applications because of their low density, biodegradability and excellent specific mechanical properties. Many plant fibers including hemp, jute, sisal, flax, ramie, coconut, pineapple leaf, kenaf, etc., have been already used for polymer reinforcements. These fibers have been aptly called lingo cellulosic fibers because most of them contain both hemicellulose and lignin along with cellulose. Although lignin and hemicellulose in cell wall serve to hold cellulose molecules and provide mechanical properties to plants, in fabricating composites, lignin and hemicellulose can lower the mechanical properties by weakening the interfacial fiber/resin adhesion. As a result, these components are commonly removed by alkali treatment. Alkali treatment is the most common process used for natural fibers such as cotton and is known as mercerization. NaOH or KOH solution could be used to remove the lignin, wax and hemicellulose in order to increase the crystallinity of fibers. Also, because of the removal of lignin and hemicellulose, increased fiber surface roughness can be achieved which, in turn can provide large surface area and better fiber/resin interaction. (Kim. & Netravali, 2010)

II. Cellulose-Based Nanofibers

Micro-cellulose fibers can also be converted into Nano-cellulose materials by mechanical processes including grinding, ultrasonic treatment and high-pressure homogenization that provide high shear stresses to isolate them into single Nano-fibrils. Common cellulose materials can be divided into cellulose Nano-fibrils and cellulose nanocrystals. Micro fibrillated cellulose (MFC), which have fibrils from microscale to nanoscale, have much higher aspect ratio with average diameter of about 10~30 nm and length to microscale. The 3-D network-like or entangled structure of MFC not only has high crystallinity but also provides significantly larger surface area to interact with resin and provides improved dispersity of fibers within the resin. Another Nano-cellulose material is cellulose nanocrystal. After strong acid hydrolysis, the C-O-C bonds of MFC are further broken, preferably in the amorphous parts and help turn cellulose nanofibers and microfibers into much shorter Nano-rods with lengths in the range of only hundreds of nanometers. While most Nano-cellulose products are primarily made from various wood pulps, CNC and MFC have also been extracted and extensively studied from other fibers from abundant plants such as hemp, kenaf, bagasse, bamboo, to agricultural by-product including coconut hulls, banana peels, wheat or rice straw. These Nano-cellulose materials from by-product sources not only provide similar properties when reinforcing polymer resin but also make full use of plant wastes. Bacterial cellulose (BC), secreted by bacteria such as acetobacter xylinum, is also a type of cellulose nanofiber. BC have high purity of cellulose and smaller diameter rather than MFC. Typical, BC have higher reinforcement properties than plant-based MFC. (Lu. & Hsieh, 2010)

CHAPTER THREE

3. Material and Methods

Avocado seed and coffee husk are the main raw material that were used in the production of the bio plastic.

3.1. Materials

3.1.1. Chemicals

Glycerol- glycerol was used as a plasticizer.

Sodium hydroxide – it was used to remove certain amounts of lignin and hemicellulose from the surface and completely remove pectin, wax, oils and other organic compounds.

Hydrogen peroxide – it was used as bleaching agents.

Deionized (DI) water – it was used for rinsing/washing.

Acetic acid – it was used to facilitates the polymerization process by disordering or breaking down the first polymer

3.1.2. Equipment's

Blender - used to mix and crush the raw avocado seed

Mixer – a mixer was used to mix the avocado seed powder with deionized water

Crusher – a crusher was used to reduce the size of raw materials into pieces

Grinder – a grinding machine was used to convert raw material into powder.

Drier – a dryer was used to remove moisture from raw materials

Filter – a filter was used to separate solid and liquid used during treatment

Decanter – a decanter was used to separate the starch form water through pouring process

Desiccator – a desiccator was used to prevent moisture absorption of bioplastic film form the atmosphere.

Cheesecloth – used for filtration or as a filter to separate fine particle, which are AVS starch from liquids or mixed solution.

Hot air oven – at hot air oven was used for sterilization of bioplastic film and for drying purpose the starch and alkali and bleached coffee husk.

3.2. Method Used for Bioplastic Production

3.2.1. Extraction of Starch

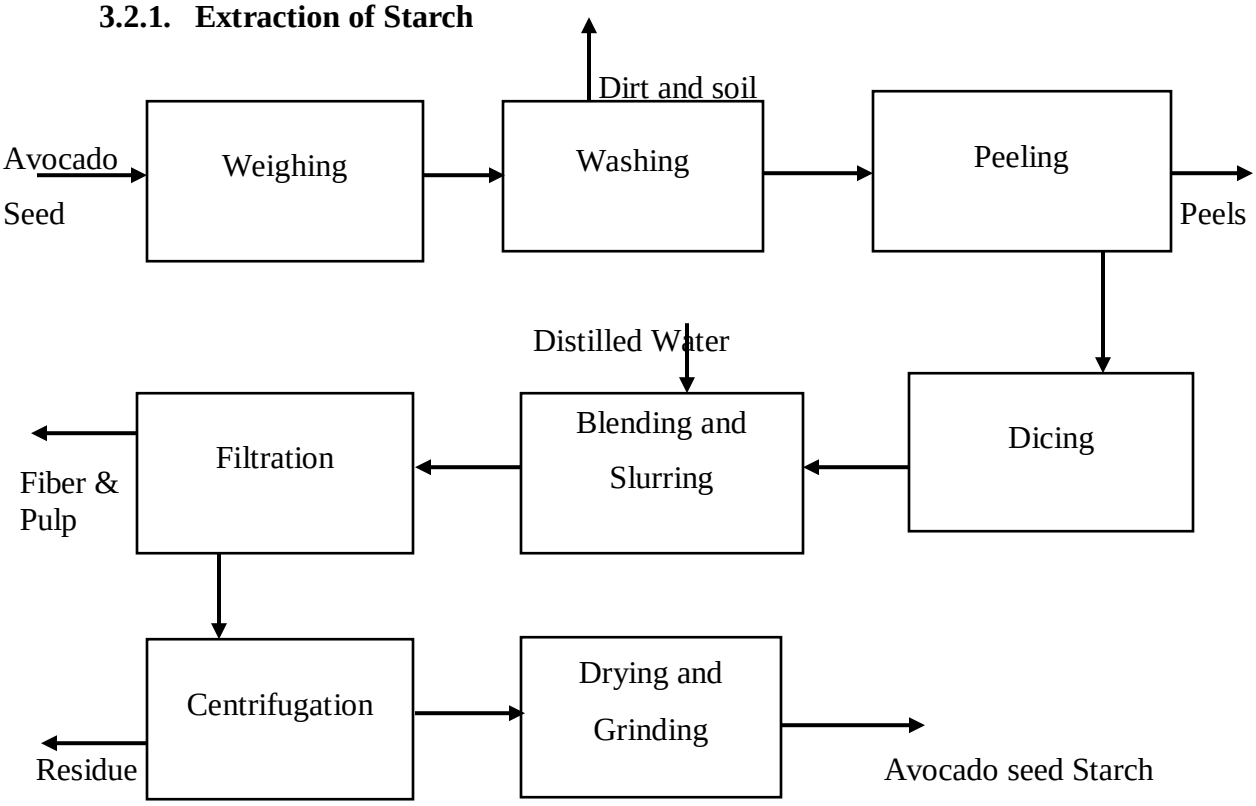


Figure 3.1. Overall process of starch extraction

There are various techniques to extract starch from avocado seed such as wet milling (water extraction), enzymatic treatment and alkali extraction. For extraction process, water medium was chosen because it was observed that the extraction rate was enhanced as compared to alkali extraction. With alkali medium, the extraction of starch from Avocado seed is decreased as compared to other tubers such as the family of Colocasia. (Moorthy, 1990).

Preparation of the avocado seed. There were a few procedures followed before the extraction of the starch from the avocado seed. These included the:

- Weighing
- Washing
- Peeling & Dicing

A. Weighing

The selected Avocado seed was first weighed. This was done to obtain an initial mass of the tuber. Avocado seed tubers with a total weight of approximately one kilogram were used in the extraction. The ratio of the impurities to the Avocado seed was then determined by the difference in the weighing before and after washing.

B. Washing

The selected Avocado seed was then washed with water to remove the contaminants such as dirt, soil, small roots and other unwanted plant materials which could otherwise affect the final output of the tuber. The rubbing in the washing step is an important quality factor since this step was determine the purity factor of the avocado seed. There are many impurities that are similar to the final starch. To avoid any contamination in the final product, proper washing was done (International Starch Institute, 2006).

The washed Avocado seed was again weighed to obtain the difference in the weighing before and after washing.

C. Peeling

The washed avocado seed was then hand peeled using a knife. Care was taken to avoid unnecessary peeling of the avocado seed. This would otherwise cause loss of the seed and starch granule from the avocado seed resulting in starch loss. A large amount of damaged starch granule could lead to alteration in the physiochemical properties of the starch to be extracted according to the procedure chosen. The peels obtained from the avocado seed can be sent to an organic compost company for further processing that can be consequently used as an organic fertilizer in the Avocado agricultural lands instead of chemical fertilizers. This would reduce the plantation cost of the farmers.

D. Dicing

The peeled Avocado seed was then carefully diced to small regular cubes of similar size (as far as possible the dimensions of all the cubes were respected). Care was taken to avoid damage of the avocado seed. Figure 3.2 shows the dices avocado seed tubers.

Figure 3.2. Diced avocado seed

E. Blending and Slurring

The blending and slurring procedure of the avocado seed sample was done in water by using a blender. This type of slurring is done for the avocado seed because the tissues are soft and require no grinding as compared to hard plant tissues such as for cereal or legume grains according to the protocol adopted (Thava Vasanthan, 2001).

Figure 3.3. Crushed and blended avocado seed

F. Water Slurring

For water slurring of the sample of diced avocado seed, the ratio of the tuber to water added was 1: 10 (w/w). For the sample of 200 g of diced avocado seed, a total mass of 2000g (2L) of water was added, that is eleven times more water by weight. During the water slurring, crushed ice was added to the mixture to avoid heat-induced damage to the starch granule (Thava Vasanthan, 2001). However the total weight of water added was carefully controlled.

Figure 3.4. Water Slurring of the avocado seed

G. Filtration

The filtration procedure was done by passing the slurry obtained through double-layered cheesecloth. The filtration procedure was done to separate the starch granules extract from the residue of the avocado. The starch was washed into the filtrate by spraying water from a wash bottle onto the residue. The lack of opacity of the filtrate, Squeezing of the cheesecloth was avoided. The residue of the avocado seed was blended two more times and filtered again to maximize recovery of the starch from the avocado seed.

Final Starch

After the mixture was left for 2days the liquid was decanted and the slurry part, which the starch of the avocado seed was left. The figure, A show the wet starch after decantation process was carried out and figure, B shows the starch poured and flatted in metal plate

(A) (B)

Figure 3.5. Slurry starch and wet starch of avocado seed

To summarize the procedure taken to extract the starch from the avocado seed, the following step are the step taken to produce the starch.

For extraction of starch from Avocado seed, the following procedure were implemented

First the raw avocado seed was washed with water and left to dry naturally with the sun. Then the AVS was crushed with and kitchen blender and sieved with a mesh of 1mm diameter 200gram of AVS powder was mixed with 2Liter of distilled water by manual stirring for 1 hour and then the mixture was mixed with a mixer for 1 hour with 500rpm and a torque of (8.2 - 8.4) N.m. The mixture was filtered using a cheesecloth. The solid part contained mostly ash, residue of seed coat and other undissolved parts remained on the cheese cloth, while most of the starch passed through the cheese cloth. The filtrate was allowed to settle for 3 h until the starch granules precipitate.

The supernatant, which contained dissolved soluble sugars, soluble protein, etc., was decanted. The precipitated part, which contained most of the starch, was collected and further washed with distilled water three times and poured on to metal plate to dry in oven at 100℃ for 1hr. The dried avocado starch was grounded in a kitchen blender for 5 minutes and then passed through 250 μm screen to obtain purified avocado seed starch (AVS) powder. The dried AVSS was weighed with a balancer.

3.2.2. Extraction of Cellulose from Coffee Husks

For extraction of Cellulose from Coffee husk, the following procedure were implemented

Frist the coffee husk was measured with a balancer. The 90 gram of CH was washed twice with tap water and taken to the oven to dry. The dried CH was crushed and sieved with a mesh of 1mm radius twice. The alkali treatment was carried out with 225 ml of 1 M NaOH solution with 90g of CH powder at a temperature of 100℃ for 3h under continuous stirring. Then the solid was filtered and washed with distilled water several times until the alkali solution was completely removed (i.e. a pH of 6.8-7 was reached). This treatment was repeated twice. The alkali treated CH powder was dried in the hot air oven at temperature of 100℃ for 30minutes and was crushed and sieved with a mesh of 250μm screen.

For bleaching treatment, 112.5ml of 1 M of NaOH solution and 506.25 ml of 10% of hydrogen per oxide with 45g of dried alkali treated coffee husk at temperature of 100℃ for 3h. The process was repeated as many times as necessary until the sample was completely white. After that the sample was filtered and washed with distilled water several times until the solution was

completely removed. Finally the wet bleached Coffee husk cellulose was poured on to a metal plate and taken to a hot air oven at 100℃ to dry for 30minutes. Then the CNC from coffee husk was weighed.

3.2.3. Production of Bioplastics

As mention in the literature part bioplastics can be produced from plant raw or waste material. And this bioplastics can be reinforced with cellulose extracted from different source in our case coffee husk. The following procedure are one without cellulose addition and the other with cellulose reinforcement.

For production of bioplastic without the addition of cellulose, the following procedure were implemented

2g of dried avocado seed starch was diluted with 40ml distilled water in a 500ml beaker. The beaker was brought on a heater plate including a magnetic stirrer. A magnet stick was added in the beaker and let stirring at 2 rpm.

5ml of 5% of acetic acid (vinegar) was pipetted in the mixture and 5ml of glycerol was added. The heater was switched to 100℃ and the mixture was allowed to heat for about 15 minutes. The stirrer was brought to 3 r.p.m as the mixture was hardening. The mixture took about 30 minutes to form an opaque gel or to become gelatinized. The gelatinized film was spread on a Petri dish. The sample was allowed to dry at 60℃ in air circulating oven for 24 hours.

For production of bioplastic with cellulose, the following procedure were implemented

The weight proportions of 1.7: 0.3 of dried avocado seed starch and CNC from coffee husk with 40ml distilled water in a 500ml beaker was rigorously stirred with speed of 100 r.p.m. to prevent aggregation. The beaker was brought on a heater plate including a magnetic stirrer. A magnet stick was added in the beaker and let stirring at 2 rpm.

5ml of 5% of acetic acid (vinegar) was pipetted in the mixture and 5ml of glycerol was added. The heater was switched to 100℃ and the mixture was allowed to heat for about 15 mins. The stirrer was brought to 3 r.p.m as the mixture was hardening.

The mixture took about 30 minutes to form an opaque gel or to become gelatinized. The gelatinized film was spread on a Petri dish. The sample was allowed to dry at 60℃ in air circulating oven for 24 hours.

CHAPTER FOUR

4. Result and Discussion

4.1. Characterization of Extracted Avocado Seed Starch (AVS)

Starch yield (%) =

[Weight of isolated starch (g) /Weight of the AVocado seed sample (g) x 100%]

Whereas:

Weight of the grounded avocado seed sample = 200g

Weight of isolated starch = 48.3g

$$\text{Starch yield (\%)} = \left[\frac{48.3\text{g}}{200\text{g}} * 100\%\right] = 24.15\%$$

From 200g of avocado seed 24.15% or 48.3 g of starch can be produced, which gave brown colored starch with particle in the size less than 100 micro meter.

As it was done on experiment, purified AVS powder was obtained by removing the impurities including protein, sugars and ash using simple washing technique. Therefore, the components of avocado raw seed powder before and after purification (AVS) are different. After purification overall starch content significantly increased 24.5% since the impurities such as protein, fibers, fat, sugars and ash all decreased during purification. The purity of AVS was sufficiently high for cross linking and using it as resin fabricating green composites.

The solubility of starch granules was tested in water at room temperature; Starch granules are insoluble in water at room temperature. However, when temperature is raised around 55-60℃ starch granules allow water to penetrate the cell wall and start swelling. The granules continue to swell as they absorb more water and finally rupture. Once inside, water acts as a plasticizer and breaks the crystalline structure of starch. Additionally, the effect of temperature on viscosity of avocado starch suspension was observed. The viscosity of avocado starch suspension is changed as the temperature is increased from room temperature (25℃) to 90 ℃. As a temperature goes above 90 ℃ the granules start rupturing and allow starch molecules to come out. As a result, the viscosity rises rapidly.

4.2. Characterization of Extracted Cellulose from Coffee Husk

CNC yield (%)

$$=\left[\left[\text{Weight of isolated cellulose (g)}/\text{Weight of the coffee husk sample (g)}\right] \times 100\%\right].$$

Weight of the coffee husk sample before treatment = 90g

Weight of isolated cellulose = 30g = (30g / 90g) *100% = 33.33%

A yield of CNC prepared was 33.33% with white odorless granular powder.
By treatment of coffee husk both hemicelluloses and lignin were removed without affecting the cellulose. Before treatment, coffee husk consists of impurities such as ash, hemicelluloses and lignin. Therefore, the content of cellulose was increased around 33.33% after combination of alkali and bleaching treatments.

Table 4.1. Sensory evaluation of color, texture, & physical appearance for the bioplastic

Bioplastic ratio of AVS to cellulose	Color	Texture	Physical appearance
1:0	Brownish-yellow	Moist	
0.75:0.25	lightly brownish	Slightly moist	
0.5:0.5	Yellowish	Sticky	

These properties are essential since they are significant factors affecting the quality perception of the produced product. The results for the color analysis above the table present the influence of AVS and Cellulose fiber concentrations in forming the bioplastic.

It is found that the bioplastic color of the 100% AVS is brownish yellow; meanwhile, the bioplastic color of the 75% fiber is light-yellow. The bioplastic colors indicate the percentage of AVS to Cellulose fiber, where the highest AVS content results in the more brownish bioplastic

color, as shown in Table above. It is also noticed that the brownish-yellow of the bioplastic color changed to light-yellow as the concentration of AVS decreases. This is due to white color of cellulose fiber, Increase of cellulose fiber concentration makes the brownish color of bioplastic become faded.

In the case of texture analysis, it is found that the texture of bioplastic depends on the concentration of cellulose. The bioplastic becomes dryer and harder as the cellulose concentration increases compared low concentration. Besides, the presence of cellulose decreases the moisture content of bioplastic. A bioplastic with 75% cellulose is dryer than the low cellulose concentration.

Table 4.2. Drying time of bioplastic film

Bioplastic ratio of AVS to cellulose fiber (kg:kg)	Drying time (in days)
1:0	5
0.75:0.25	4
0.5:0.5	3
0.25:0.75	2

Table 4.2 shows the drying time of bioplastics at different AVS to cellulose fiber ratios. From the observation, bio plastic 1:0, AVS to cellulose fiber takes the longest drying time (5 days) and followed by the 0.75:0.25 with four days, 0.5:0.5 with three days, and 0.25:0.75 with 2 days. This indicates that the level of cellulose have effect on the drying time of bioplastic. As the concentration of cellulose increases the drying time decreases. The incorporation of higher AVS and low fiber contents in production of bio plastic would increase the drying time. This indicate the fiber takes less time to dry.

Water absorption of film was determined by

$$\text{Water absorption (\%)} = [\frac{Mf-Mi}{Mf}] * 100$$

Where, M_f = Wet weight

M_i = Dry weight

Table 4.3. Effect of cellulose and plasticizer on water uptake of film

Bioplastic film sample	Cellulose (g)	Glycerol (ml)	Dry weight in (g)	Wet weight in (g)	Water uptake (%)
1	0.25	2	2.0	2.8	28.6
2	0.5	4	2.0	2.5	20
3	0.75	6	2.0	2.35	15
4	1	8	2.0	2.25	11.1

The table above shows that, the water uptake decreased as the content of cellulose increased for bioplastics with cellulose content of 0.25, 0.5, 0.75 and 1g. Furthermore, starch was more sensitive to water because of its hydrophilic nature than cellulose. But the monomers of cellulose are connected with more chemical bonds than in starch. This makes cellulose very strong and insoluble in water, unlike starch.

From the table, it can observe that the water absorption of the plasticized film decreased with the increase of glycerol concentration. This is due to that the glycerol forms a strong hydrogen bond with starch, preventing the water molecule from combining with the plasticizer or starch. As a plasticizer, (glycerol), forms hydrogen bonds with starch, it destroys the current hydrogen bonds between hydroxyl groups in starch molecules. This is due to the forming of new hydrogen bonds between glycerol and hydroxyl groups. As a result, the plasticizing effect of the starch is enhanced; making it more difficult for water molecules to penetrate plasticized films.

Water solubility of film was determined by

$$\text{Solubility (\%)} = [\frac{Wi-Wo}{Wi}]$$

Wi = initial weight

Wo = final weight

Table 4.4. Effect of plasticizer on solubility of film

Bioplastic film sample	Glycerol (ml)	Initial weight in (g)	Final weight in (g)	Water solubility (%)
1	2	2.0	1.6	20
2	4	2.0	1.55	27.5
3	6	2.0	1.40	30
4	8	2.0	1.30	35

The table above shows that, the water solubility increases as the amount of plasticizer increased for bioplastics with plasticizer content of 2, 4, 6, and 8ml. The table above shows that due to the hydrophilic nature of plasticizers, they perform essential role in weakening the interaction between polymer molecular chains increasing the free space volumes between the chains (reduced intermolecular attraction forces, and grew the free volume of the system). This in turn promotes water diffusion into the film matrix and, consequently, increasing the solubility of plasticized films.

Table 4.5. Effect of cellulose on solubility of film

Bioplastic film sample	Cellulose (g)	Initial weight in (g)	Final weight in (g)	Water solubility (%)
1	0.25	2.0	1.3	35
2	0.5	2.0	1.40	30
3	0.75	2.0	1.55	27.5
4	1	2.0	1.60	20

From the table, it can observe that the water solubility of the film decreased with the increase of Cellulose concentration. From the data, it can be concluded that the more degree of Cellulose, the fewer level of water solubility of the film.

This indicates that the combination of cellulosic fiber with starch improves water resistance to a certain degree since, as already known, Cellulose is hydrophilic material, although its hydrophilicity is lower than starch.

Biodegradability Test

Bioplastic samples (1x1 cm) were buried in soil, and then incubated at room temperature for 7 days. The buried samples were then cleaned from the soil by scrapping and weighed. The weight loss of the bioplastics was calculated using equation

$$\text{Weight loss (\%)} = \frac{(wo-wf)}{wo}\text{x}100$$

Wo = the initial sample weight, wf = the final sample weight

The initial weight of bioplastic sample was 2g and after 7 days burial is 1.65g, therefore the its weight loss was 17.5%.

CHAPTER FIVE

5. Material and Energy Balance

5.1. Material Balance

Material balances are fundamental to the control of all processing, particularly in the control of yields of the products. The basis for both of these observations is the law of conservation of mass, which states that mass can neither created nor destroyed. This is done by formulating a material balance for the different units of operation used.

5.1.1. Material Balance of Starch Purification

0 0 0

Accumulation = In + Generation – Consumption – Out

In = Out

Mass in = Mass out

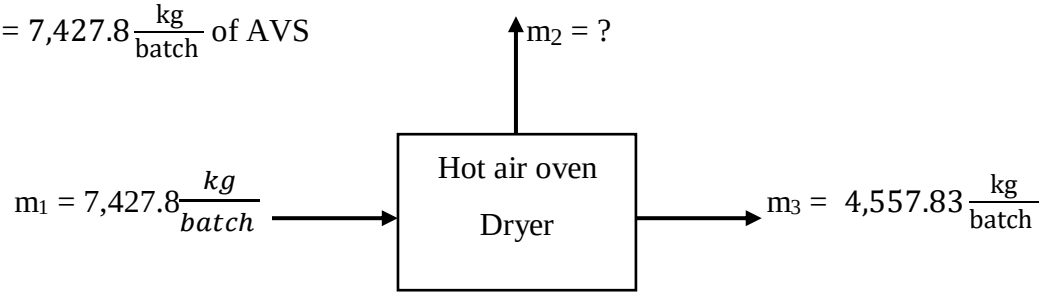
Basis: for material balance of starch purification

- 330 working day per year
- 6 batch per day
- Amount of avocado seed needed per year 14,707.044 ton per year
- Amount of distilled water needed per batch 146,921.94 m^3 per year

DW – Distilled water

m_2, amount of moisture

$m_1 = 7{,}427.8 \frac{kg}{batch}$ of AVS



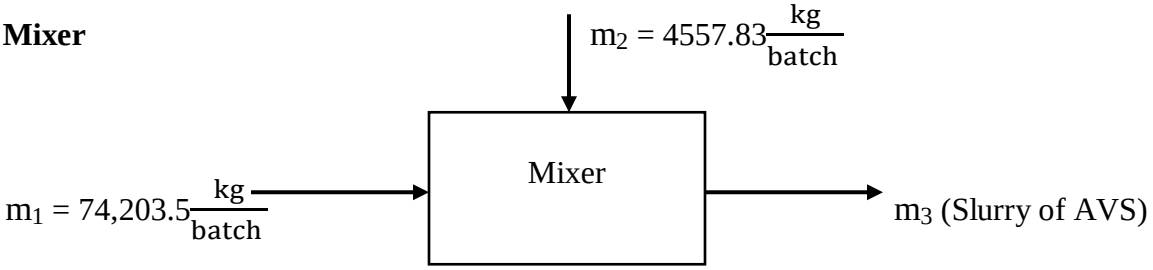
$m_1 = m_2 + m_3$

$m_2 = m_1 - m_3$

$m_2 = 7{,}427.8 \frac{kg}{batch} - 4{,}557.83 \frac{kg}{batch}$

$m_2 = 2869.97 \frac{kg}{batch}$

MB on Mixer



m_1, distilled water

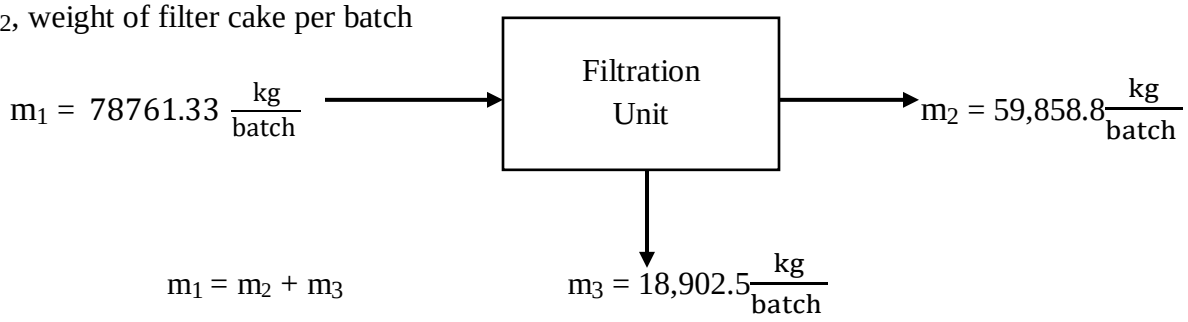
$m_1 + m_2 = m_3$

$m_3 = (74{,}203.5 + 4557.83) \frac{kg}{batch}$

$m_3 = 78{,}761.33 \frac{kg}{batch}$

MB on Filtration unit

m_2, weight of filter cake per batch



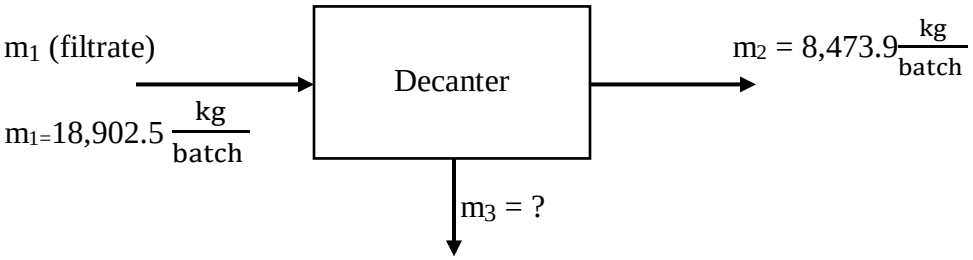
$m_1 = m_2 + m_3$

$m_3 = m_1 - m_2$

$m_3 = (78{,}761.33 - 59{,}858.8)$

$m_3 = 18{,}902.5 \frac{kg}{batch}$

MB on Decanter



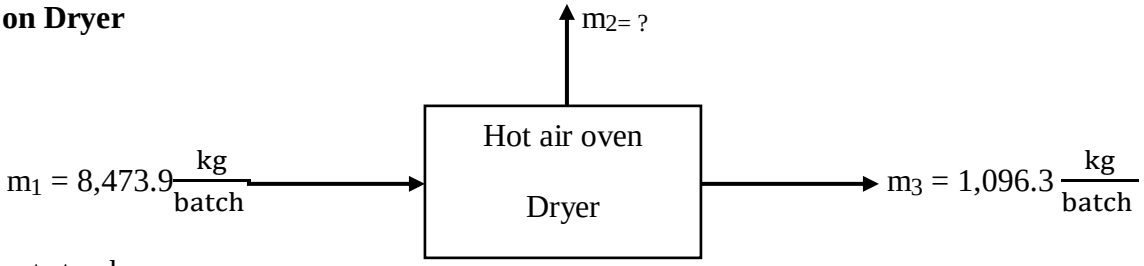
$m_1 = m_2 + m_3$

$m_3 = m_1 - m_2$

$m_3 = 18,902.5\text{-}8,473.9$

$m_3 = 10,428.6 \ \frac{kg}{batch}$

MB on Dryer



m_1, wet starch

m_2, moisture

m_3, dry starch

$m_1 = m_2 + m_3$

$m_2 = m_1 - m_3$

$m_2 = 7,647.6 \ \frac{kg}{batch}$

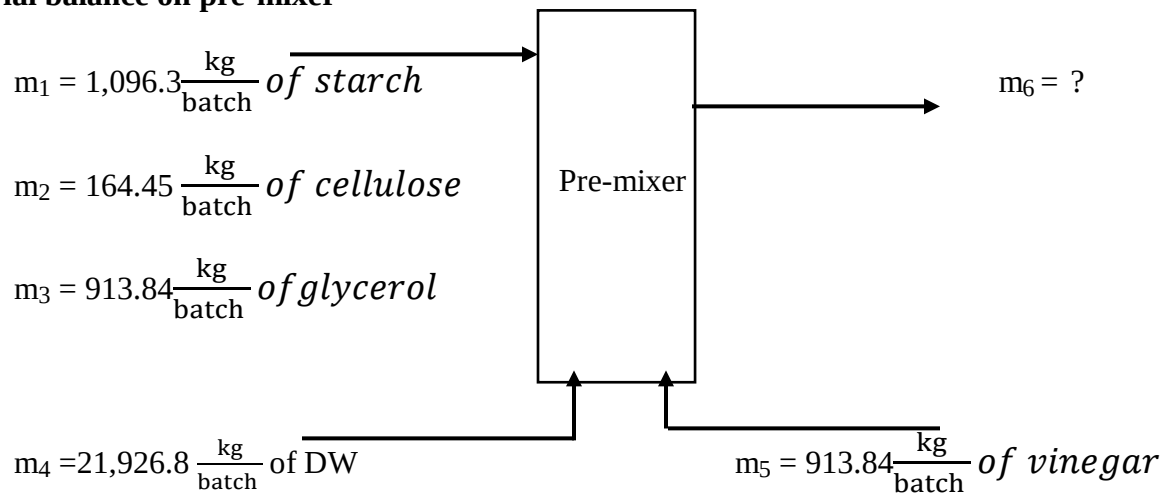
Material Balance on Bioplastic film production

Basis:

- 330 working day per year
- 6 batch per day
- Amount of cellulose needed per year is 325.6011 ton per year
- Amount of glycerol and Vinegar needed per year is 1809.4032 m^3

- Amount of distilled water needed per year is 43,415.064 m^3

Material balance on pre-mixer


m1 = 1,096.3 kg/batch of starch
m2 = 164.45 kg/batch of cellulose
m3 = 913.84 kg/batch of glycerol
Pre-mixer
m6 = ?
m4 =21,926.8 kg/batch of DW
m5 = 913.84 kg/batch of vinegar

m_1, weight of starch per batch

m_2, weight of cellulose per batch

m_3, weight of glycerol per batch

m4, weight of distilled water per batch

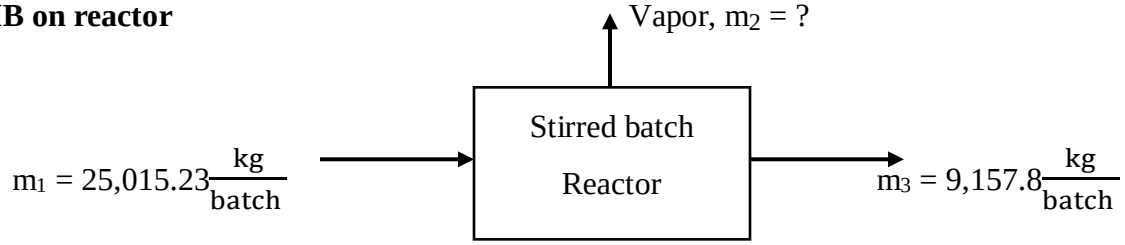
m5, weight of vinegar per batch

$$m_6 = m_1 + m_2 + m_3 + m_4 + m_5$$

$$m_{6=} = (1{,}096.3 + 164.45 + 913.84 + 21{,}926.8 + 913.84)\frac{kg}{batch}$$

$$m_6 = 25{,}015.23\frac{kg}{batch}$$

MB on reactor



$$m_1 = m_2 + m_3$$

$$m_2 = m_1 - m_3$$

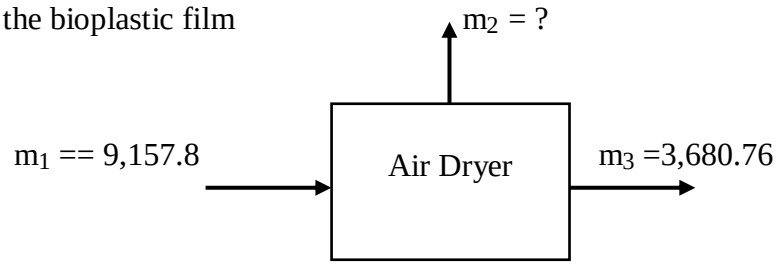
$$m_2 = (25{,}015.23 - 9{,}157.8)\frac{kg}{batch} = 24{,}103.4\frac{kg}{batch}$$

MB on dryer

m_1, weight of gelatinized starch per batch

m_2, weight of the moisture output per batch

m_3, weight of the bioplastic film



$$m_1 = m_2 + m_3$$

$$m_2 = m_1 - m_3$$

$$m_2 = (9{,}157.8 - 3{,}680.76)\ \frac{kg}{batch}$$

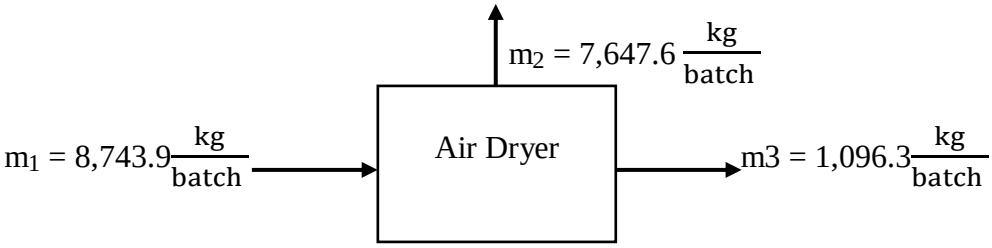
$$m_2 = 5{,}477.04\ \frac{kg}{batch}$$

5.2. Energy Balance

The beginning of any design problem is to quantify the different energy involved in the process. Energy balances are used in the examination of the various stages of a process, over the whole process, and even extending over the total production system from the raw material to the finished product. Energy quantities can be described by energy balances, which are statements on the conservation of energy.

5.2.1. Energy Balance on Dryer of Starch Purification

Energy balance on dryer



Assumption;

- Drying is taken place at atmospheric condition
- Steady state condition
- The loss of heat occurred is negligible

Specific heat, Cp of AVSS = 3.01 $\frac{kJ}{kg\,k}$

Latent heat of vaporization of water is = 2257$\frac{kJ}{kg\,k}$

Inlet temperature is 25^0C

Outlet temperature is temperature is 100^0C

The heat energy required for drying is given by;

Q = heat energy required to raise T^0 to 100^0C + Latent heat to remove water

$Q = m_s \times Cp_s\,(\Delta T) + m_w \times \lambda v$

$= 8{,}743.9\frac{kg}{batch} \times 3.01\frac{kJ}{kg\,k} \times (100^0 - 25^0)\,K + 7{,}647.6\frac{kg}{batch} \times 2257\frac{kJ}{kg}$

$= 1{,}973{,}935.4\frac{kJ}{batch} + 17{,}260{,}633.2\frac{kJ}{batch}$

$= 19{,}234{,}568.6\frac{kJ}{batch}$

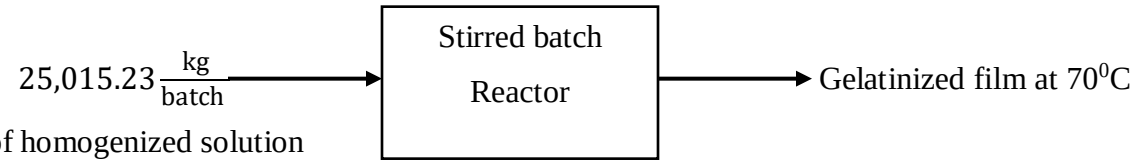
Q = 1,335.73KW

Energy balance on reactor

Given data

- Mass of homogenized solution = 25,015.23$\frac{kg}{batch}$
- Gelatinization temperature is 70^0C
- Cp of starch of avocado = 3.01 $\frac{kJ}{kg\,k}$
- Cp of vinegar = 3.804 $\frac{kJ}{kg\,k}$
- Cp of coffee husk cellulose = 1.4 $\frac{kJ}{kg\,k}$

- Cp of glycerol = 2.35 $\frac{kJ}{kg\,k}$
- Cp of distilled water = 4.2 $\frac{kJ}{kg\,k}$
- Mass of starch = 1,096.3$\frac{kg}{batch}$
- Mass of cellulose = 164.445 $\frac{kg}{batch}$
- Mass of glycerol = 913.84 $\frac{kg}{batch}$
- Mass of distilled water = 21,926.8$\frac{kg}{batch}$
- Mass of vinegar =913.84 $\frac{kg}{batch}$



Assumptions;

- Steady state
- Gelatinization temperature at 70^0C
- Potential energy(PE)and kinetic energy (KE)many be neglected

$\Delta U + \Delta KE + \Delta PE = Q - Ws$

$\Delta U + \Delta KE + \Delta PE = Q - Ws$

$\Delta U + Ws = Q$ since, $\Delta H = \Delta U + Ws$

$Q = \Delta H = m \times (h_2 - h_1)$ …… Eq(1)

$Q = m \times Cp\ (T_2 * T_1)$ but $Cp = Cp_{mix}$

$Cp_{mix} = \sum_{i=1}^{n} Xi\ Cpi$

$Cp_{mix} = \sum_{i=1}^{n} \frac{Mi}{Mmix} Cpi$

$Cp_{mix} = \left(\frac{M1}{Mmix}\right) Cp_1 + \left(\frac{M2}{Mmix}\right) Cp_2 + \left(\frac{M3}{Mmix}\right) Cp_3 + \left(\frac{M4}{Mmix}\right) Cp_4 + \left(\frac{M5}{Mmix}\right) Cp_5$

$Cp_{mix} = \left(\frac{1096.3}{25015.23}\right) \times (3.01) + \left(\frac{164.445}{25015.23}\right) \times (1.4) + \left(\frac{913.84}{25015.23}\right) \times (2.35) +$

$\left(\frac{21{,}926.8}{25015.23}\right) \times (4.2) + \left(\frac{913.8}{25015.23}\right) \times (3.804)$

$Cp_{mix} = (0.132 + 0.0092 + 0.086 + 3.68 + 0.14) \frac{\text{kJ}}{\text{kg k}}$

$Cp_{mix} = 4.04 \frac{\text{kJ}}{\text{kg k}}$

Therefore; $Q = m\, Cp_{mix}\ (T2 - T1)$

$Q = 25{,}015.23 \times \left(3.925 \frac{kJ}{kg*K}\right) \times (90 - 25)^0\text{C}$

$Q = 4{,}554{,}708.9 \frac{\text{kJ}}{\text{batch}}$

Q = 316.3KW of heat was supplied to achieve gelatinization temperature of 90^0C

CHAPTER SIX

6. Equipment Sizing and Economic Analysis

6.1. Designing of Process Equipment

6.1.1. Designing of Crusher

Size reduction equipment is classified into crushers and grinders. Crushers are used to reduce large solid materials into feed sizes for grinding. Grinding machines are used for reducing crushed particles into their smallest functional sizes. Examples of grinders include attrition mills, roll compression mills, fluid energy mills and ball mills the crushing of any particle takes place when the applied external forces are greater than the cohesion among molecules of a particle.

These dimensions are design decisions, which depend on desired input particle size, the feed rate and maximum output particle size.

Specifications:

Diameter, D is 120mm,

Width, W, of each roll is 150mm, and

The maximum roll gap, l, is 5mm.

Roll pressure, P= 20 MPa

Tensile strength of the roll, σt = 410MPa

Thickness of the Roll (t)

A hollow cylindrical shaft is used to build the roll, this hollow shaft's thickness must be calculated to check for its ability to withstand the compressive strength of the hardest of all the rocks.

$$\sigma t = \frac{P*D}{2t}$$

$$t = \frac{P * D}{2\sigma t}$$

Where,

t = Thickness of the roll

σt = Tensile strength of the roll & P = Roll pressure

Substituting into Equation above, and taking the design factor of 1.4 to account for the wide range of material harness, yields,

$$t = \frac{20\text{Mpa} * 120\text{mm}}{2 * 410\text{Mpa}} = 6.74\text{mm}$$

Design Calculation of Shaft Diameter Design based on Strength

The shaft diameter is given by:

$$D^3 = \frac{16}{\pi\, Ss}\sqrt{(Kb \times Mmax)^2 + (Kt \times Mt)^2}$$

Where, Kt = Motor Sensitivity

Kb = Back EMF

Ss = Shear stress

M_{max} = Maximum moment

M_t = torsional moment.

Data: Kb =1.5 and Kt =1.0 Ss = 40MN /m^2 (Shear stress for mild steel)

M_{max} = 43.7Nm, M_t = 137.21Nm

$$D^3 = \frac{16}{\pi \times 40 \times 10^6}\sqrt{(1.5 \times 43.7)^2 + (1 \times 137.21)^2}$$

$$D^3 = 1.273 \times 10^{-7}\sqrt{4296.8 + 18826.58}$$

$$D^3 = 1.94 \times 10^{-5}$$

$$D = \sqrt[3]{1.94 \times 10^{-5}}$$

D = 0.02686m = 26.9mm

Design Calculation of Shaft Diameter based on Torsional Rigidity

$D^4 = \frac{584\, Mt * L}{G\, \Theta}$ from the above given data Mt= 1372.21Nm

L = 500mm = 0.5m

Θ = 0.5

$$G = 80 \times 10^9\ Nm^{-2}$$

$$D^4 = \frac{584 \times 137.21 \times 0.5}{80 \times 10^9 \times 0.5}$$

$$D^4 = 1.002 \times 10^{-6}$$

$$D = \sqrt[4]{1.002 \times 10^{-6}}$$

$$D = 0.0316m = 31.6mm$$

6.1.2. Reactor Sizing

Space between jacket and reactor vessel depend on the size of the vessel which typically range from 50 mm for small vessel to 300 mm for large vessel.

A gap 75 mm is selected as space between the two.

Diameter of jacket DJ =2.64 m

Diameter of vessel DV = 2.5 m

Cooling fluid used is the Cooling Water.

Cooling Jacket area available (A) = π/ 4* ($DJ^2 - DV^2$)

= π /4 *($2.643^2 - 2.5^2$)

= 0.58 m^2

Since the reactor is cylindrical

V= $(DV/2)^2$ *H but, H/D = 1.5 and

H = 2.5×1.5 = 3.75 m

V = $(2.5/2)^2$ *3.75

= 18.4 m^3 and assume, 10% allowance

= 20.24 m^3

Wall thickness of the reactor

Working Pressure of Vessel (P) = 200 kPa

Density of the material (ρ) = 1,200 kg/m3

Joint Efficiency, Ej = 0.80

Material of Construction = Carbon Steel

Maximum allowable pressure =1,795.8 kpa

Static Pressure (P) = (ρ∗g∗H) /1,000

= (1,200∗9.81∗2.053)/ 1,000

= 24.14 kpa

Total Pressure (Ps) = Pst + P = 224 kpa

Maximum allowable pressure = 1.25* pt

Maximum allowable pressure = 1.25*224

= 280.2 kpa

= 2.802 bar

Thickness (t) = $(Pi*Di)/((2f*j) - Pi)$

= (286∗2.5) /((2∗0.8∗1795)−286)

= 31 mm

Assume corrosion allowance (A) = 2 mm

Therefore, wall thickness = 31 + A

= 31 + 2

= 33 mm

6.1.3. Designing of Dryer

Basis of the design = 1 hour operation

Density of solid, wet avocado starch 900kg/m3

From energy balance, Q =1,335.73KJ

Q = Ma ΔH

Where Ma = Mass of air

ΔH = Change in enthalpy of air = Ho – Hi

Hi = Enthalpy of air 25 ºc

Ho = Enthalpy of air 100 ºC

Hi @ 25 ºc = 300.4kJ/kg and

Ho@ 100 ºc = 381kJ/kg

Q = Ma ΔH

Ma = Q/ΔH

= 1,335.73KJ/80.6KJ/kg

Hence Ma = 16.6 kg

Density of air at 100 ºC = 0.946 kg/m3

Volume of air at 100 ºC = 17.6 m3

Flash tube

The flash dryer is basically a pneumatic dryer. Hence, the diameter and the length of the flash tube can be calculated using equations for a pneumatic column. The calculations are presented below. Minimum carrying velocity, Vm Minimum carrying velocity can be obtained from the relationship below

$$V_m = 565.78\left(\left[\frac{\rho_s}{\rho_s + 997.95}\right]D_2^{0.6}\right)$$

Where D = Diameter of particle

Assume Diameter of particle = 1.5 mm

Therefore Vm = 5.4 m/s

To prevent settling, the actual velocity is multiplied by a factor to obtain the Actual Carrying Velocity. Assuming a factor of safety of 1.1, we have:

V_{actual} = Vm × factor of safety

= 5.96 m/s

Duct internal diameter

Vs = Volume of solids

= Ms /ρs

= 1267.6kg/900kg/m3 =1.41 m^3

Hence the total volume is Vt = (Va +Vs) = (17.6+1.41)m3 = 18.93m^3

And volumetric flow rate is Q = Vt /3600 = 0.00526 m^3 /s

The pipe diameter is obtained by using the equation given by

$$ID = 0.6392\sqrt{\frac{Q}{v}}$$

Where ID = Internal diameter (inches)

V = Flow velocity (ft/s)

Hence, ID = 0.01995m

= 19.95 mm

6.2. Economic Analysis

The purpose of this part was to present a preliminary technical and economic feasibility study for the process plant. Two main aspects were examined, namely the total capital investment of the process plant and the payback period. The economic analysis of the biodegradable plastic process plant was estimated by calculating the following:

1. Purchase Equipment Cost (PEC)
2. Total Direct Cost (TDC) and Total Indirect Cost (TIC)
3. Fixed Capital Investment (FCI)
4. Total Capital Investment (TCI)
5. Total Product Cost (TPC)
6. Profit or Loss
7. Pay Back period
8. Internal Rate of Return (IRR)

The method used, such as the equations and relationships, for the economic estimation was from the book of Max S. Peters, Klaus D. Timmerhaus, 1991, Plant Design and Economics for Chemical Engineers.

Purchase Equipment Cost

The first aspect of the economic analysis was the Purchase Equipment cost. The prices of the equipment to be used in the process plant were first obtained from different industries specialized in the field of starch extraction and biodegradable plastic production.

Some of the purchased equipment cost includes;

- ❖ All equipment listed on a complete flowsheet
- ❖ Spare parts and non-installed equipment spares
- ❖ Surplus equipment, supplies, and equipment allowance
- ❖ Inflation cost allowance
- ❖ Freight charges
- ❖ Allowance for modifications during start-up

Table 6.1. Equipment cost and the industrial source

Equipment Name	Industrial Source	Amount	Price (USD)
Conveyor	Kaifeng Sida Agricultural Products Equipment Co.,Ltd	2	3400
Cleaning Cage	Kaifeng Sida Agricultural Products	1	1060
Crusher (rasper)	Kaifeng Sida Agricultural Products Equipment Co.,Ltd	1	3500
Round Sieve (rotating sieve)	Kaifeng Sida Agricultural Products Equipment Co.,Ltd	4	9200
Slurry Pump	Kaifeng Sida Agricultural Products Equipment Co.,Ltd	5	7500
Round Sieve (Dewatering)	Kaifeng Sida Agricultural Products Equipment Co.,Ltd	1	2300
Residue Pump	Kaifeng Sida Agricultural Products Equipment Co., Ltd	5	6500
Vortex Assembly (Hydrocyclone)	Kaifeng Sida Agricultural Products Equipment Co.,Ltd	18	63000
Desander	Kaifeng Sida Agricultural Products Equipment Co.,Ltd	2	800
Desander Pump	Kaifeng Sida Agricultural Products Equipment Co.,Ltd	1	1600
Vacuum dehydrator	Kaifeng Sida Agricultural 1Products Equipment Co.,Ltd	1	9600

Airflow dryer	Kaifeng Sida Agricultural Products Equipment Co.,Ltd	1	26000
Electricity	Kaifeng Sida Agricultural Products Equipment Co.,Ltd	5	7000
Transfer Pump	Kaifeng Sida Agricultural Products Equipment Co.,Ltd	5	3000
Hydrolysis Tank	Hangshou Haishun Pharmaceutical Machinery Co., Ltd	1	191076
Dryer	KC Printing Machine limited	1	3850
Granulating and Recycling unit	Jiangsu Lianguan Science & Technology Development Co.,Ltd.	1	152947
Plastic extruder	Wenzhou Zhudian Machinery Co., Ltd.	1	250808
Film and Surface treatment	Tianrun Machinery Co., Ltd.	1	4282

(Source: Kaifeng Sida Agricultural Products Equipment, 2016)

The Purchased equipment cost (PEC) was calculated by adding the different price of the equipment and the total purchased equipment cost was $747,423.

Equipment Cost Estimation

Some of the equipment costs were estimated by using the equation from estimating equipment costs by scaling (S. Peters et al., 1991)

The equipment that were estimated by scaling are:

- Hydrolysis tank
- Granulating and recycling unit
- Extruder unit
- Film surface treatment

The equation below was used for the estimation of the costs of the equipment.

Cost of equipment A = cost of equipment B $\times \left[\frac{Capacity\ of\ Equipment\ A}{Capacity\ of\ Equipment\ B}\right]^{0.6}$ ..... Eq. (1)

1. Hydrolysis Tank
   - Capacity of hydrolysis tank from quotation = 10kg/hr.
   - Capacity of hydrolysis tank required = 100kg/hr.
   - Cost of equipment obtained = 100 000 USD
   - Estimation of hydrolysis tank required:

Cost of equipment A = $(75500\ USD) \times \left[\frac{94}{26}\right]^{0.6}$

Cost of equipment A = 191,076 USD

Table 6.2. Capacity and cost of equipment

Equipment	Capacity	Wanted capacity	Actual price	Final price
Hydrolysis tank(L)	20000	94000	75500	191076
Granulating and recycling unit (kg/hr)	300	2000	49000	152947
Extruder (kg/hr)	100	1000	63000	250808
Film surface treater (kg/hr)	120	1000	1200	4282

Total Direct Cost (TDC) and Total Indirect Cost

The TDC and the TIC were then calculated by using the typical percentages of Fixed Capital Investment values for TDC and TIC segments for multipurpose plants or large additions to existing facilities from Cost factors in Capital Investment (Max S. Peters et al., 1991)

Direct costs

The equation was used to find the direct cost.

Direct Cost = Percentage used x Purchased Equipment Cost

The table below shows the typical percentages and cost calculated for the direct cost.

Table 6.3. Total Direct Cost calculations

Direct costs	% taken	PEC (USD)	Calculations	Costs (USD
Purchased Equipment installation	0.39	747422.57	39% × PEC	2914948.42
Instrumentation & control	0.13	747422.57	13% × PEC	97164.95
Piping	0.31	747422.57	31% × PEC	231700.99
Electrical equipment & Materials	0.10	747422.57	10% × PEC	74742.27
Building & Services	0.29	747422.57	29% × PEC	216752.5
Yard Improvement	0.10	747422.57	10% × PEC	74742.27
Service facilities	0.55	747422.57	55% × PEC	67439.8
Land	0.06	747422.57	6% × PEC	44845.4
Total Direct cost (TDC)				1,442,526

The TDC was obtained by adding all the direct cost and the value is 1,442,526 USD.

Indirect Costs

The equation was used to find the indirect cost.

Indirect Cost = Percentage used x Total Direct Cost

The table below shows the typical percentages and cost calculated for the indirect cost.

Table 6.4. Total Indirect Cost calculations

Indirect Costs	% taken	PEC	Calculations	Costs (USD)
Engineering & supervision	0.32	747422.57	32% × PEC	239175.22
Construction expenses	0.34	747422.57	34% × PEC	254123.7
Construction fee	0.18	747422.57	18% × PEC	134536.04
Contingency	0.36	747422.57	36% × PEC	269072.13
Total Indirect Cost (TIC)				896,907

The TIC was obtained by adding all the indirect cost and the value is 896,907 USD.

Fixed Capital Investment (FCI)

The FCI was obtained by using the equation:

Fixed Capital Investment = Total Direct Cost + Total Indirect Cost

FCI = TDC + TIC

FCI = 1,442,526 + 896,907

FCI = 2,339,433 USD

The FCI of the process plant is 2,339,433 USD.

Total Capital Investment (TCI)

The TCI has the following equation:

Total Capital Investment = Fixed Capital Investment + Working Capital

TCI = FCI + WC

Assumption:

The percentage of the WC assumed was 10% of the TCI.

When the WC represents a percentage of 10%,

TCI = FCI + 0.01 TCI

When the FCI of the process plant is 2,339,433 USD

Then:

TCI = (FCI/ 0.9)

TCI = $(^{2339433}/_{0.9})$ = 2,599,370 USD

Therefore WC = (0.1 x 25,599,370) = 259,937 USD

Total Product Cost (TPC)

The TPC was calculated from the from Ratio factors for estimating capital-investment items based on delivered equipment cost (S. Peters et al.,1991) and the calculations are shown in Table below.

Table 6.5. Total Product Cost (TPC) calculations

Raw materials	Calculations	USD	USD
Avocado seed	0.687 USD X 1000kg x330 days	226804.124	
Acetic acid	692 USD x 1.621 metric ton x330days	370171.56	
Glycerol	0.7 USD x 1.907 metric ton x330days	440.52	
	Total		2748548.6
Operating Labor (OL)	10% TPC	0.1 TPC	
Direct Clerical Labor	10% OL	0.01 TPC	

Utilities	10% TPC	0.1 TPC	
Maintenance & repairs	5% FCI	116,972	
Operating Supplies	0.5%	FCI 11697.15	
	Direct Production Cost		2877217.4+ 0.21 TPC
Fixed Charges	10% TPC	0.1 TPC	
Plant Overhead Cost	10% TPC	0.1 TPC	0.2 TPC
	Manufacturing Cost		2877217.4+ 0.41 TPC
Administrative cost	3% TPC		
Distribution & Selling			
	General Expenses		0.08 TPC
	Total Production Cost (TPC)		2877217.4+ 0.49 TPC

TPC = USD (2877217.4+ 0.49 TPC)

TPC = 5,641,603 USD

The value obtained for the TPC was 5,641,603 USD

Sales

The sales of the bioplastic film produced from the starch based polymer were sold at 0.86 USD and the total sales obtained from the sale of 22084.56 kg /day starch-based biodegradable plastic film was:

Total sales = (22084.56 x 0.86 USD x 330 days)

= 6,261,112 USD

The revenue for the process plant is 6,261,112 USD

Profit/Loss

The Profit/ Loss of the process plant was calculated by using equation:

Profit/Loss = Revenue – TPC

When the revenue of the process plant is 6,261,112 USD and the TPC is 5,641,603 USD

The Profit encountered by the process plant is = (6,261,112 – 5,641,603) USD

= 619,509 USD

After calculating the revenue and total product cost, the process plant obtained a profit of 619,509 USD

Payback Period

The payback period of the process plant was determined by using the equation:

$$\text{Payback period} = \left(\frac{\text{Total capital investment}}{\text{profit per year}}\right)$$

$$\text{Payback period} = \left(\frac{\text{TCI}}{\text{profit or loss per year}}\right)$$ When:

- TCI of the plant is 2,599,370 USD
- The Profit obtained per year is

The payback of the process plant = $\left(\frac{2{,}599{,}370}{619{,}509}\right)$

= 4.20 years

Return on Investment (ROI)

Return on Investment (ROI) = $\left(\frac{\text{net profit per year}}{\text{Total capital investment}}\right)$

Assume the project is New Capacity with established corporate market positions which have low level of risk and have range of minimum acceptable return after income tax (***mar)***, percent / year is between 8-16 % / year. And also assume that the depreciation was included in net profit and tax rate of 35%

The net profit obtained is given by

The net profit = profit per year x (1-tax rate)

= 619,509 x (1-0.35)

= 402,680.85

Return on Investment (ROI) = $\left(\frac{402,680.85}{2,599,370} * 100\%\right)$

= 15.5%

The calculated value of ROI, **15.5%** is within the range (8-16 %) that was given above. Therefore, the project is acceptable.

Table 6.6. Economic analysis summation table

Economic feature calculated	Value	Conversion (1$ = 45Birr)
Purchase Equipment Cost (PEC)	747,422.57 USD	33,634,015.65
Total Direct Cost (TDC) and	TDC: 1,442,525.56 USD	64,913,650.2
Total indirect Cost (TIC)	TIC: 896, 907.08 USD	40,360,818.6
Fixed Capital Investment (FCI)	2,339,432.7 USD	105,274,471.5
Total Capital Investment (TCI)	2,599,369.6 USD	116,971,632
Total Product Cost (TPC)	5,641,602.7 USD	253,872,121.5
Sales/ year	6,261,112 USD	281,750,040
Profit or loss	619,508.84 USD	27,877,897.8
Payback Period	4.20 years	-
Return on investment	15.5%	-

From the economic analysis, a final payback period of 4.20 years was obtained for a total profit of 619,509 USD per year and a Total Capital Investment (TCI) of 2,599,370. The production of approximately 7,287,904.8 Kg of starch-based biodegradable film was possible per year at a selling price of 0.86 USD thus bringing revenue of 6261,112 USD to the process plant per year.

CHAPTER SEVEN

7. Environmental Impact of Bioplastic Production

Materials such as starch, cellulose, wood, sugar, and biomass are used as a substitute for fossil fuel resources to produce bioplastics; this makes the production of bioplastics a more sustainable activity compared to conventional plastic production. The environmental impact of bioplastics is often debated, as there are many different metrics for "greenness" (e.g., water use, energy use, deforestation, biodegradation, etc.). Hence bioplastic environmental impacts are categorized into nonrenewable energy use, climate change, eutrophication, and acidification. Bioplastic production significantly reduces greenhouse gas emissions and decreases non-renewable energy consumption. Firms worldwide would also be able to increase the environmental sustainability of their products by using bioplastics. (Gironi, F. and Vincenzo, P. 2011)

7.1. Environmental Health & Bioplastic

Although bioplastics save more nonrenewable energy than conventional plastics and emit less GHG compared to conventional plastics, bioplastics also have negative environmental impacts such as eutrophication and acidification.] Bioplastics induce higher eutrophication potentials than conventional plastics. Biomass production during industrial farming practices causes nitrate and phosphate to filtrate into water bodies; this causes eutrophication, the process in which a body of water richness gains excessive richness of nutrients. Eutrophication is a threat to water resources around the world since it causes harmful algal blooms that create oxygen dead zones, killing aquatic animals. Bioplastics also increase acidification. The high increase in eutrophication and acidification caused by bioplastics is also caused by using chemical fertilizer in the cultivation of renewable raw materials to produce bioplastics. (Madeleine, R. and Claire, Y. 2013)

Other environmental impacts of bioplastics include exerting lower human and terrestrial eco-toxicity and carcinogenic potentials compared to conventional plastics. However, bioplastics exert higher aquatic eco-toxicity than conventional materials. Bioplastics and other bio-based materials increase stratospheric ozone depletion compared to conventional plastics; this is a result of nitrous oxide emissions during fertilizer application during industrial farming for biomass production. Artificial fertilizer increase nitrous oxide emissions especially when the

crop does not need all the nitrogen. Minor environmental impacts of bioplastics include toxicity through using pesticides on the crops used to make bioplastics. Bioplastics also cause carbon dioxide emissions from harvesting vehicles. Other minor environmental impacts include high water consumption for biomass cultivation, soil erosion, soil carbon losses and loss of biodiversity, and they are mainly are a result of land use associated with bioplastics. Land use for bioplastics production leads to lost carbon sequestration and increases the carbon costs while diverting land from its existing uses. (Weiss et al., 2012)

Although bioplastics are extremely advantageous because they reduce non-renewable consumption and GHG emissions, they also negatively affect the environment through land and water consumption, using pesticide and fertilizer, eutrophication and acidification; hence one's preference for either bioplastics or conventional plastics depends on what one considers the most important environmental impact.

Another issue with bioplastics, is that some bioplastics are made from the edible parts of crops. This makes the bioplastics compete with food production because the crops that produce bioplastics can also be used to feed people. These bioplastics are called "1st generation feedstock bioplastics". 2nd generation feedstock bioplastics use non-food crops (cellulosic feedstock) or waste materials from 1st generation feedstock (e.g. waste vegetable oil). 3rd generation feedstock bioplastics use algae as the feedstock. (Gironi, F. and Vincenzo, P. 2010)

With the degradation of ecosystems, many countries are turning their attention to environmental issues. While governments enforce relevant regulations, industries have started to develop their own codes of conduct, limit the use of chemicals and overhaul manufacturing operations.

Types of Environmental assessments

The assessment covers:

- Environmental management system
- Energy and greenhouse gas emission
- Air emissions
- Water
- Wastewater
- Chemical management & Land use and biodiversity nuisances

7.2. Environmental Impact of Assessment

Bioplastics are alternatives of conventional petroleum-based plastics. Bioplastics are polymers processed from renewable sources and are biodegradable. This study aims at conducting an environmental impact assessment of the bioprocessing of agricultural wastes into bioplastics compared to petro-plastics using an LCA (life cycle assessment) approach. Bioplastics were produced from avocado seeds in laboratory. In a biochemical reaction under heating, starch was extracted from seeds and glycerin, vinegar and water were added with a range of different ratios, which resulted in producing different samples of bio-based plastics. Nevertheless, the environmental impact of the bioplastics production process was evaluated and compared to petro-plastics. A life cycle analysis of bioplastics produced in laboratory and petro-plastics was conducted. The results are presented in the form of global warming potential, and other environmental impacts including acidification potential, eutrophication potential, freshwater eco-toxicity potential, human toxicity potential, and ozone layer depletion of producing bioplastics are compared to petro-plastics. The results show that the greenhouse gases (GHG) emissions, through the different experiments to produce bioplastics, range between 0.354 and 0.623 kg CO_2 eq. per kg bioplastic compared to 2.37 kg CO_2 eq. per kg polypropylene as a petro-plastic. The results also showed that there are no significant potential effects for the bioplastics produced from avocado seeds on different environmental impacts in comparison with poly-β-hydroxybutyric acid and polypropylene. Thus, the bioplastics produced from agricultural wastes can be manufactured in industrial scale to reduce the dependence on petroleum-based plastics. This in turn will mitigate GHG emissions and reduce the negative environmental impacts on climate change. (Mohamed et al., 2021)

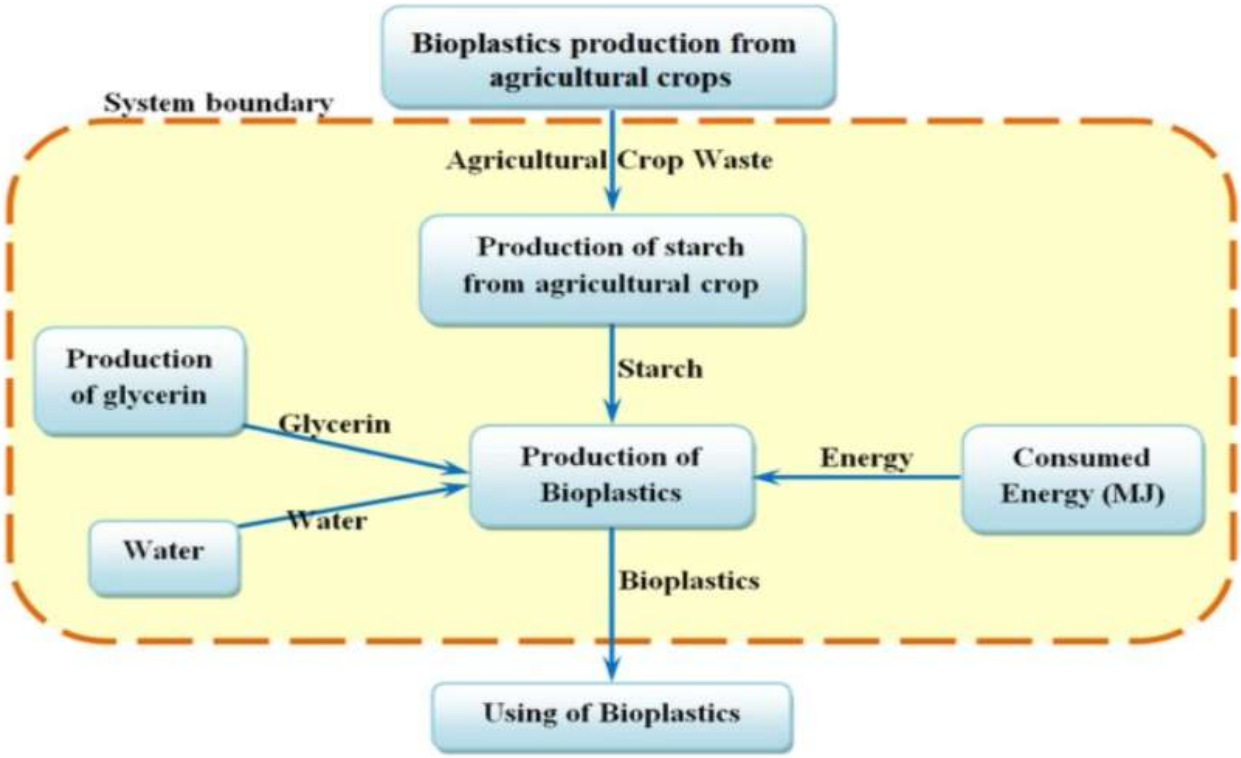


Figure 7.1. Assessment of the organic bioplastic production source

(Samer, M. *et al.*, Clean Techn Environ Policy, 2021)

CHAPTER EIGHT

8. Conclusions and Recommendations

8.1. Conclusions

From this study, starch from avocado seed and cellulose from coffee husk are the main source of raw material for the production of bioplastic. The bioplastic was successfully produced from using such raw materials. There are various techniques to extract starch from avocado seed such as wet milling (water extraction), enzymatic treatment and alkali extraction. For extraction process, water medium (wet milling) was chosen because it was observed that the extraction rate was enhanced as compared to alkali extraction and enzymatic extraction. With alkali medium, the extraction of starch from Avocado seed is decreased as compared to other tubers. The experimental conditions that increase the starch production yield from Avocado seed wastes was evaluated in this research in order to determine how the extraction parameters, techniques and sedimentation time, affect the starch production yield and purity. For this study the wet extraction method is used for starch extraction from Avocado seed wastes. Moisture content in Avocado seed wastes was an average 39%. The starch yield was 48.3g obtained from the original 200 g wet Avocado seed waste samples, representing yields varying from 24.5% from dry mass. Higher starch yields was obtained with higher sedimentation time and better extraction technique so called wet extraction method. Starch extraction from Avocado seed wastes has proven potential for waste use and obtaining value-added products.

Also the experimental condition that increases the cellulose yield from coffee husk was evaluated in this research in order to determine how the extraction techniques affect the cellulose extraction yield and purity.

The bioplastic film produced was characterized in terms of water uptake, water solubility, and biodegradability depending on the amount of cellulose and plasticizer used. In this study, the water uptake of 28.6,20, 15 and 11.1% decreased as the content of cellulose increased for bioplastics with cellulose content of 0.25, 0.5, 0.75 and 1g respectively.

The reason was evaluated as the monomers of cellulose are connected with more chemical bonds than in starch. This makes cellulose very strong and insoluble in water, unlike starch. Also the

water solubility, 20, 27.5, 30, and 35% increases as the amount of plasticizer increased for bioplastics with plasticizer content of 2, 4, 6, and 8ml respectively was evaluated. It can observe that the water solubility of the film decreased with the increase of Cellulose concentration. So it can be concluded that the more degree of Cellulose, the fewer level of water solubility of the film. Also the degree of biodegradability was tested and found to be 17.5%.

The economic feasibility of the project was tested by using a feasibility test. The payback period and rate of investment on the project were 4.2 years and 15.5% respectively. And finally, the environmental impact of bioplastic production was assessed.

8.2. Recommendation

The recommendation identified for this thesis are as follows:

- It is good to use fresh avocado seed starch for a better quality of bio-plastics production.
- The waste extracted from the avocado seed and fibers could be used as compost or cattle feed.
- A cheaper and less risky form of acid could be used instead of hydrochloric acid such as acetic acid.
- A sorbitol can be used as a plasticizer instead of glycerol for bio-plastic production.
- To achieve maximum production of bioplastic using the Avocado seed feedstock, the optimum conditions should be studied and compared with those produced from non-renewable sources and to improve the technology that enhances the production process, consequently achieves higher bioplastic production.
- The equipment in the laboratory is not enough to experiment. Well-organized laboratory work is necessary to determine the quality parameter of bio-plastic produced from Avocado seed starch. So that the institution should supply enough equipment to carry out experiments without any distraction.

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